

# CEMENT AND CEMENT MANUFACTURE

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## Modification and Calibration of Kühl's Sedimentation Apparatus.

Its Practical Use in Determining the Granular Composition  
of Cement.

By K. KOYANAGI.

IN CEMENT AND CEMENT MANUFACTURE for March, 1931, a description was given of the sedimentation apparatus constructed by Prof. Dr. H. Kühl. The writer has constructed a similar apparatus, and after many experiments found that it has some defects which cause serious errors in the determination of cement fineness.

A new apparatus was therefore constructed in which the determination of diameters of the cement grains in sediments was made by direct microscopic measurements. But three-dimensional microscopic measurements require considerable skill and experience, and are not always possible in a cement plant laboratory, and the writer found that the application of Stokes's law affords an accurate method of calibration of this apparatus. In using the apparatus the writer compared the granular composition of two series of commercial cements, made by grinding in mills with air separation and in compound mills without air separation, and found some difference between them.

The general construction of the apparatus made by the writer is nearly the same as that of Kühl's. It has, however, a device for controlling the voltage of the electricity in the heat element by using a transformer, so that the temperature in the sedimentation tube can be kept nearly constant. The charging and discharging arrangements are also different. A general view of the apparatus is illustrated in Fig. 1. Figs. 2 and 3 show the charging and discharging apparatus.

The charging arrangement has a thermometer and an air agitator, both of which are lacking in Kühl's apparatus. When the test is started the temperature of the alcohol in the charging apparatus must be the same as that of the alcohol

at the uppermost end of the sedimentation tube. The mixture of cement and alcohol in the charging apparatus must be often agitated before the test is begun, because if the comparatively thick mixture of cement and absolute alcohol is

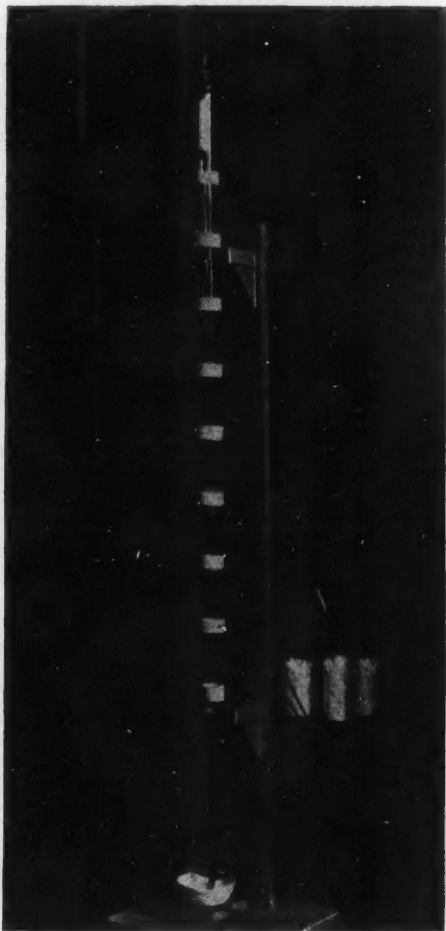


Fig. 1.—Sedimentation Apparatus.

allowed to stand still for some time without agitation, even if the alcohol is free from water, the cement shows a tendency to conglomerate, and the conglomerated cement sinks very quickly when sedimentation is begun and soon reaches the

bottom of the tube like coarser cement grains, so that the coarser sediment are not free from finest flour.

The discharging apparatus is so designed that only the sedimented cement grains can be taken out of the sedimentation tube and the volume of alcohol in the tube remains unchanged, while in Kühl's apparatus a slowly flowing stream of alcohol issues in drops from the tube which carries the cement particles out of the apparatus, so that the volume of alcohol in the sedimentation tube is changed.

The apparatus is so operated that, when sedimentation begins, the container A (Fig. 3) is filled with alcohol, and the pinchcock B is opened while other cocks are closed. The cement grains settle in A. At the end of each fraction the

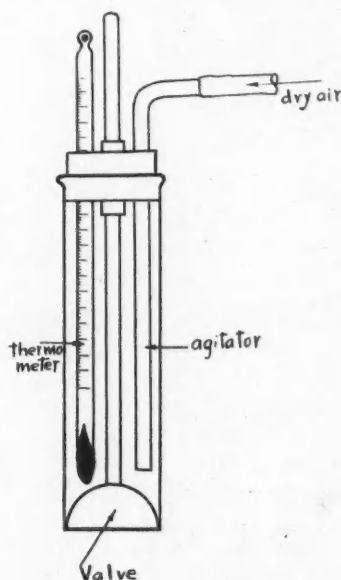


Fig. 2.—Charging Apparatus.

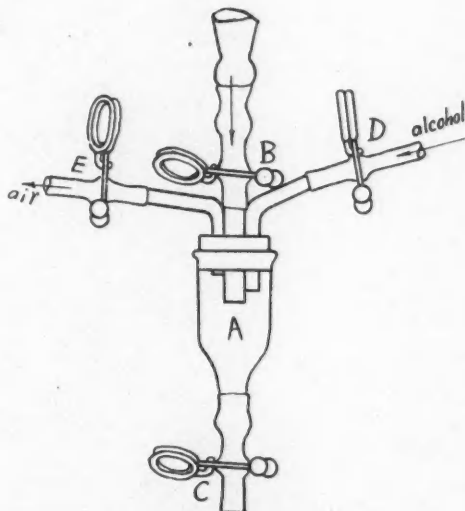


Fig. 3.—Discharging Apparatus.

cock B is closed and the contents of A are allowed to flow down into a porcelain basin beneath by opening C and E. The inner surface of A is then washed with alcohol by opening D and C, and when the sediment in A is thoroughly washed out A is again filled with alcohol by opening D and E and is prepared for the second fraction of sedimentation. By this arrangement the sediments can quickly be taken out without changing the level of alcohol in the sedimentation tube.

As the sedimentation liquid, absolute alcohol of 99 per cent. purity was used. The alcohol after use was recovered by distillation, but this is not easy because

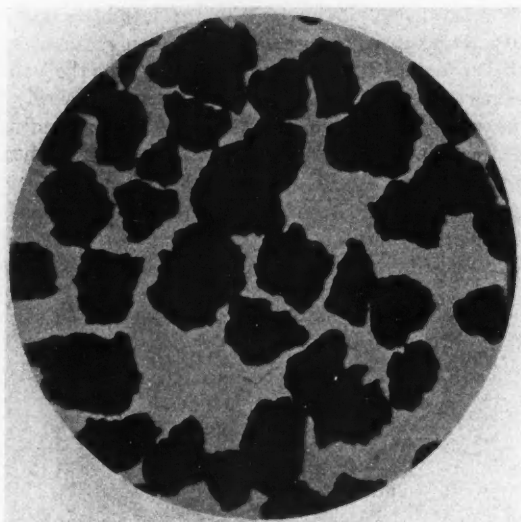


Fig. 4.—Residue of grain size greater than 100 microns on 4900 m./cm<sup>2</sup> sieve.

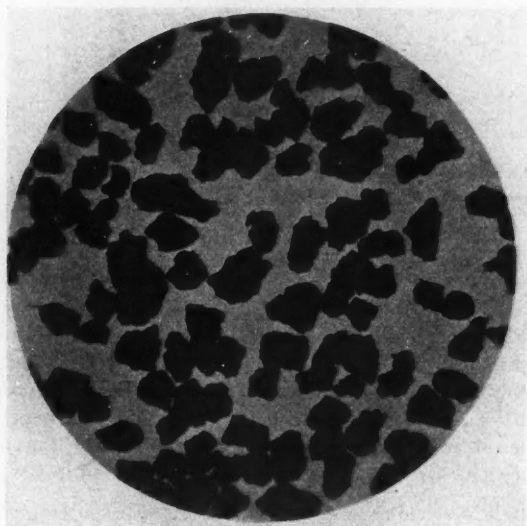


Fig. 5.—Fraction I (5 minutes); grain size 100 to 57 microns.



absolute alcohol is very hygroscopic and absorbs much water from the air during the experiment. The alcohol must be dehydrated after use, because if it contains more than 3 per cent. of water no satisfactory results can be obtained as the conglomeration of cement will occur; in other words, the finest particles adhere to the surface of the coarser ones, so the coarser sediments are not completely free from finest flour when observed under the microscope. To dehydrate the alcohol once used it is heated with freshly burnt pure quicklime for twenty-four hours and distilled. The distilled alcohol is then heated for some time with pieces of sodium metal, and again distilled. It takes some time to dehydrate the alcohol

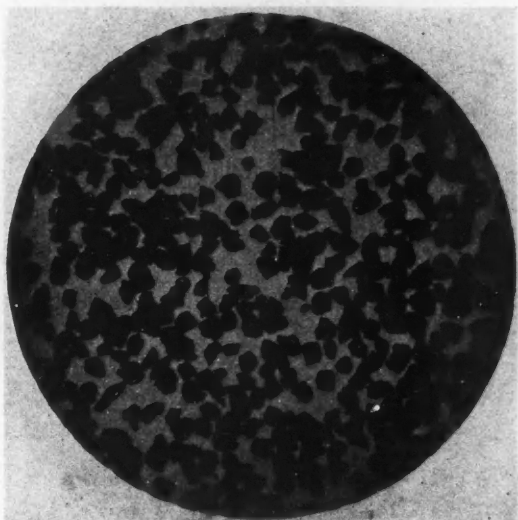


Fig. 6.—Fraction II (5 minutes); grain size 57 to 33 microns.

to the purity of over 98 per cent., and this is the greatest disadvantage of the process.

The heating arrangements are so designed that the uppermost part of the alcohol column is heated at 40 deg. C., and a temperature fall of about 15 deg. C. is set up between the top and bottom of the tube. The sample of cement for sedimentation is dried at 100 deg. C. for an hour and then passed through a sieve with 4,900 meshes per square centimetre; the part passing through the sieve is used as the sample.

The sediment was taken out of the apparatus after intervals of five, fifteen, thirty and sixty minutes, and the sizes of cement particles in each sediment were calculated by applying Stokes's formula and at the same time measured directly by a microscope. The values of calculation and direct measurements coincided

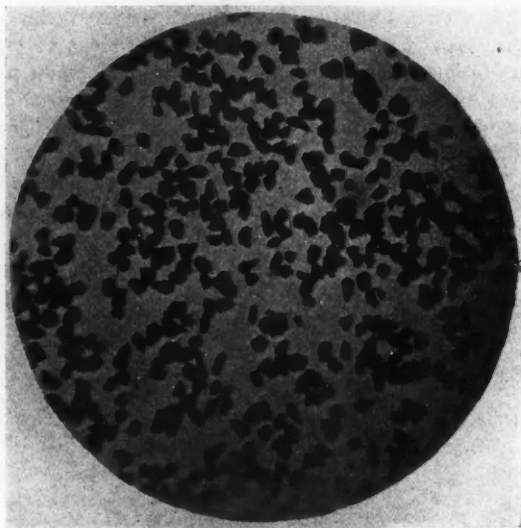


Fig. 7.—Fraction III (30 minutes); grain size 33 to 23 microns.

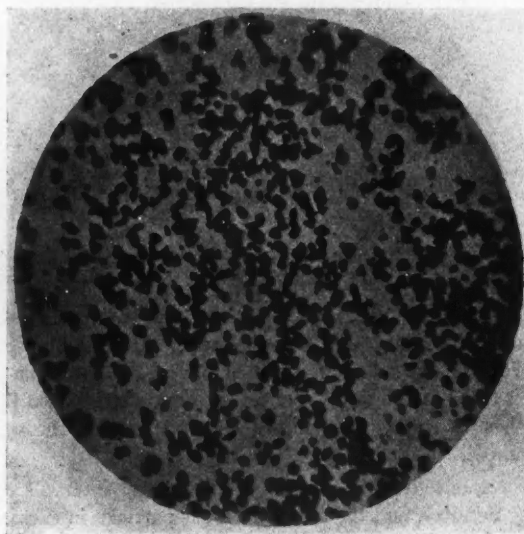


Fig. 8.—Fraction IV (60 minutes); grain size 23 to 16 microns.

well with each other. Fig. 4 shows the residue on a sieve with 4,900 meshes per square centimetre, and Figs. 5 to 8 show the finer grains obtained after sedimentation for five, fifteen, thirty and sixty minutes respectively, magnified 90 diameters.

Assuming the cement particles falling in the alcohol to be spherical in form, Stokes's law may be applied; this is expressed by the formula

$$V = \frac{2ga^2(\sigma - \rho)}{9\mu}$$

where  $V$  = terminal velocity in centimetres per second.

$g$  = acceleration due to gravity = 981 square centimetres per second.

$a$  = radius of the particles in centimetres.

$\sigma$  = the density of the falling body in grammes per cubic centimetre (for cement usually 3.1).

$\rho$  = density of the fluid in which the body is falling, expressed in grammes per cubic centimetre.

$\mu$  = viscosity of medium expressed in C.G.S. units.

$\rho$  and  $\mu$  for alcohol vary with the temperature as shown in Table I.

TABLE I.

$T$ Temperature in deg. C.	$\rho^{(1)}$	$\mu^{(2)}$
10	0.79784	0.01450
15	0.79360	
20	0.78934	0.01190
25	0.78506	
30	0.78076	0.00989
35	0.77641	
40	0.77203	0.00827

TABLE II.

$T$ Temperature in deg. C.	$\rho$	$\rho_{cal.}$	$\Delta\rho$
10	0.79784	0.79792	$-8 \times 10^{-5}$
15	0.79360	0.79362	$-2 \times 10^{-5}$
20	0.78934	0.78931	$+3 \times 10^{-5}$
25	0.78506	0.78501	$+5 \times 10^{-5}$
30	0.78076	0.78070	$+6 \times 10^{-5}$
35	0.77641	0.77640	$+1 \times 10^{-5}$
40	0.77203	0.77209	$-6 \times 10^{-5}$

TABLE III.

$T$ Temperature in deg. C.	$\mu$	$\mu_{cal.}$	$\Delta\mu$
10	0.01450	0.01450	0
20	0.01190	0.01190	0
30	0.00989	0.00989	0
40	0.00827	0.00827	0

<sup>1</sup> Circular 19, U.S.A. Bureau of Standards.

<sup>2</sup> Martin, *loc. cit.*, pp. 7, 13.

In order to obtain the values of  $\rho$  and  $\mu$  for any temperature between 10 deg. and 40 deg. C., draw the  $T - \rho$  curve and  $T - \mu$  curve on section paper by using the values in Table I, and calculate the empirical formulæ of the curves by mathematical computations. Fig. 9 shows the  $T - \rho$  curve. The empirical formula of this curve can easily be calculated by averages, and is

$$\rho = 0.80653 - 0.000861T \quad (2)$$

where  $\rho$  = density of alcohol in grammes per cubic centimetre.

$T$  = temperature in deg. C.

This is the function of a straight line, and the values calculated from this formula coincide fairly accurately with the measured values, as shown in Table II.

In the same manner the empirical formula of the  $T - \mu$  curve (Fig. 10) is calculated as follows:

$$(T + 58.97)(\mu + 0.00604) = 1.4167 \quad (3)$$

(function of a hyperbola)

The values of  $\mu$  calculated from this formula coincide with the measured values without any error, as shown in Table III.

From equations (2) and (3) we can calculate with small errors the values of  $\rho$  and  $\mu$  for any temperature between 10 and 40 deg. C.

By applying the Allen's<sup>(3)</sup> method we can calculate the limitations of size of cement particles when Stokes's law can no longer be applied. Allen's formula is

$$a^3 = \frac{9}{2} \frac{\mu^2}{g\rho(\sigma - \rho)} = \frac{9}{2} \frac{\gamma^2}{g \left( \frac{\sigma - \rho}{\rho} \right)} \quad (4)$$

where  $a$  = critical radius in centimetres.

$\mu$  = viscosity of the fluid in C.G.S. units.

$\gamma$  = kinematic viscosity =  $\mu/\rho$ .

$g$  = acceleration due to gravity = 981 square centimetres per second.

$\sigma$  = density of falling body in grammes per cubic centimetre.

$\rho$  = density of fluid in which the body is falling in grammes per cubic centimetre.

By inserting all the necessary data in this formula we can calculate the critical radius and diameter of the cement particle at all temperatures between 10 and 40 deg. C. The results are given in Table IV.

TABLE IV.

$T$ Temperature in deg. C.	Critical radius in centimetres.	Critical diameter in microns.
10	0.008068	161.36
15	0.007550	151.00
20	0.007088	141.76
25	0.006664	133.28
30	0.006281	125.62
35	0.005920	118.40
40	0.005589	111.78

<sup>3</sup> Allen, *Phil. Mag.*, 1900, I (V series), p. 323.

From this calculation we can see that Stokes's formula can be applied for all sediments in all parts of the sedimentation tube, because the cement sample used for the sedimentation test is passed through a sieve with 4,900 meshes per square centimetre, the apertures of which are 100 microns.

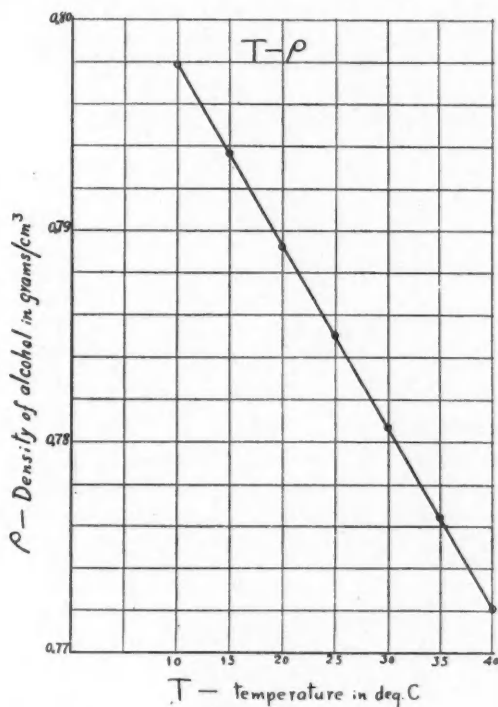


Fig. 9.

By applying Stokes's formula (1) we can calculate the velocity of cement particles in all parts of the sedimentation tube, each of which has a different temperature. By dividing the lengths of the respective parts of the tube with the corresponding velocities we can calculate the time which a grain of a definite diameter takes to fall through each part of the tube. The total sum of these times gives the time of sedimentation from the top to the bottom of the tube. The lengths of the tube parts and the corresponding temperatures when the room temperature is 25.7 deg. C. are given in Fig. 11 (see page 382). An example of this calculation is given in Table V.

The time of sedimentation of a cement grain with a diameter of twenty microns is 2,461.269 seconds, or 41.021 minutes.

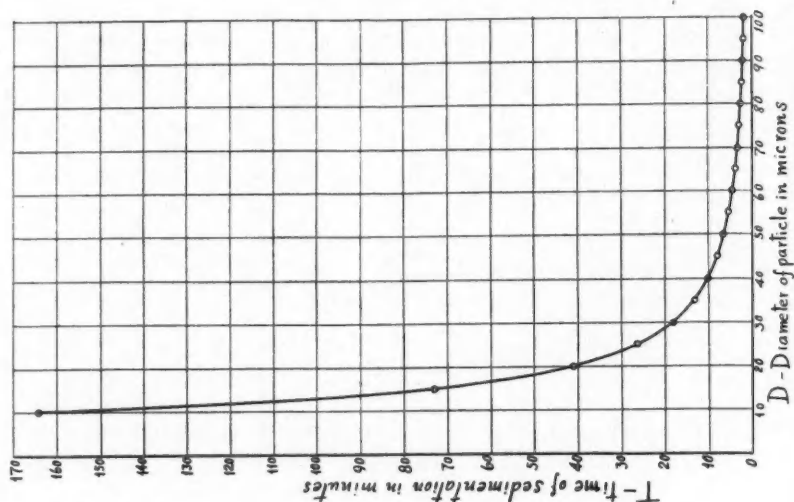


Fig. 12.

In the same manner we calculated the sedimentation times of cement particles with diameters of ten to 100 microns in minutes ; the results are given in Table VI.

When the diameters of cement particles are plotted as abscissæ and the times of sedimentation as ordinates of a rectangular co-ordinate, and the points are

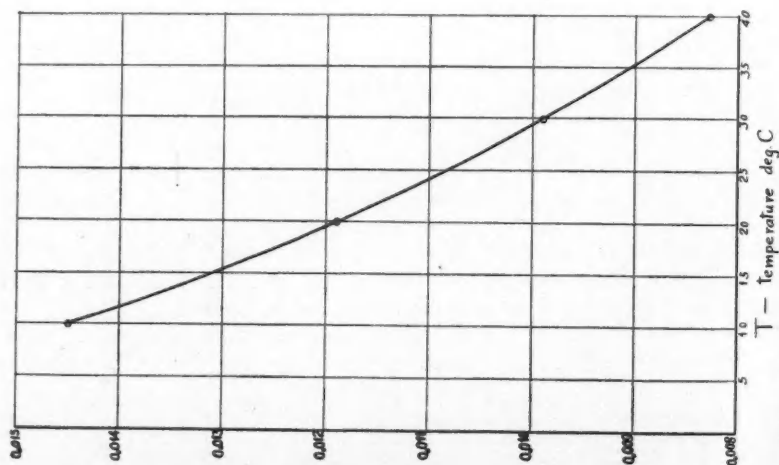


Fig. 10.— $\mu$ -Viscosity of alcohol in C.G.S. units.

TABLE V.

TIME OF SEDIMENTATION OF A CEMENT GRAIN OF WHICH DIAMETER IS 20 MICRONS,  
AT ROOM TEMPERATURE OF 25.7 DEG. C.

Tube parts.	Lengths in cm.	Temperature, deg. C.	$\rho$ in g/cm. <sup>3</sup>	$\mu$ in C.G.S. units.	Velocity in cm./sec.	Time in sec.
$P_1$	16.5	40.0	0.77203	0.00827	0.061366	268.878
$P_2$	12.2	40.0	0.77203	0.00827	0.061366	198.807
$P_3$	12.6	39.6	0.77243	0.00833	0.060914	206.850
$P_4$	12.9	37.5	0.77424	0.00865	0.058615	220.082
$P_5$	12.3	35.8	0.77571	0.00891	0.056868	216.290
$P_6$	12.8	33.5	0.77769	0.00928	0.054554	234.629
$P_7$	12.4	31.8	0.77915	0.00957	0.052868	234.547
$P_8$	12.5	30.9	0.77993	0.00972	0.05203	240.225
$P_9$	30.5	26.1	0.78406	0.01061	0.047585	640.961
Total ..						2,461.269

TABLE VI.

Nos.	D diameter of cement grain in microns.	T time of sedimentation in minutes.	T calculated from (V) in minutes.	$\Delta T$ .
1	10	164.09	164.14	-0.05
2	15	72.93	72.94	-0.01
3	20	41.02	41.02	0
4	25	26.25	26.25	0
5	30	18.23	18.23	0
6	35	13.39	13.39	0
7	40	10.26	10.25	+0.01
8	45	8.10	8.10	0
9	50	6.56	6.56	0
10	55	5.42	5.42	0
11	60	4.56	4.56	0
12	65	3.88	3.88	0
13	70	3.35	3.35	0
14	75	2.92	2.92	0
15	80	2.56	2.56	0
16	85	2.27	2.27	0
17	90	2.03	2.03	0
18	95	1.82	1.82	0
19	100	1.64	1.64	0

TABLE VII.

Fraction.	Time in minutes.	Diameter of cement grains in microns.	
		Calculated.	Directly measured.*
I	5	100—57.28	100—60
II	5—15	57.28—33.07	60—35
III	15—30	33.07—23.39	35—25
IV	30—60	23.39—16.53	25—15

\* Measured by U.S.A. Bureau of Standards method.



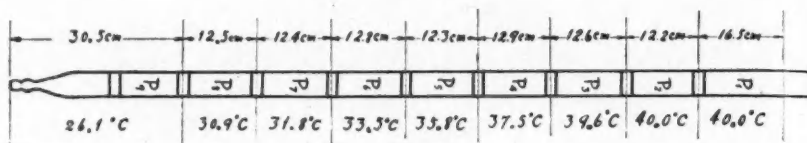


Fig. 11.

plotted, the curve shown in Fig. 12 is obtained of which empirical formula can also be easily calculated as follows :

$$\log T = 4.2155 - 2.0003 \log D$$

$$\text{or } T = 16424.8148 D^{-2.0003} \dots \dots \dots (5)$$

where  $T$  is time of sedimentation in minutes.

$D$  is the diameter of cement grains in microns.

This is one logarithmic function of a hyperbola. The calculated values of  $T$  from this formula coincide well with the original values, as shown in the last column of Table VI.

From equation (5) we can calculate the diameters of the cement grains in each fraction of sedimentation for five, fifteen, thirty and sixty minutes, which are compared with the direct microscopic measurements in Table VII.

It is generally believed that compound mills without air separators have an advantage; that compound mills grind the finest portions of cement still finer, while the use of an air separator, although it permits of low sieve residue, produces a cement containing relatively little of the finest fractions. In order to ascertain whether or not this is true, the writer tested the granular composition of commercial cements made by both grinding processes. The results are given in Table VIII. Cements Nos. 1 to 6 were ground in mills with air separators, while cements Nos. 7 to 10 were ground in compound mills without air

TABLE VIII.

Cement Nos.	1	2	3	4	5	6	7	8	9	10
Residue on the sieve 4,900 mesh/cm <sup>2</sup> in per cent. (grain size > 100 $\mu$ ) ..	1.62	1.08	1.40	0.76	0.97	3.08	1.10	2.38	1.49	1.03
Fraction I in per cent. (grain size 100—57 $\mu$ ) .. ..	17.48	10.89	11.26	9.68	12.27	15.88	8.94	11.29	6.66	7.50
Fraction II in per cent. (grain size 57—33 $\mu$ ) .. ..	27.60	26.85	25.52	25.44	25.30	20.93	21.73	23.97	20.48	20.13
Fraction III in per cent. (grain size 33—23 $\mu$ ) .. ..	14.04	15.58	15.51	16.15	14.27	12.97	14.63	13.38	15.37	14.71
Fraction IV in per cent. (grain size 23—16 $\mu$ ) .. ..	12.74	17.71	13.66	14.89	11.85	11.70	13.70	8.23	13.47	13.23
Finest flour in per cent. (grain size < 16 $\mu$ ) .. ..	26.52	27.89	32.65	33.08	35.34	35.44	39.90	40.75	42.53	43.40

separators. From the results of this test it can be clearly seen that the amount of finest flour is far greater in the cements ground by compound mills without air separators than in cements ground by mills with air separators, although the residues on a sieve with 4,900 meshes per square centimetre are nearly the same.

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## Notes from Abroad.

### New French Cement Plant.

The new works at Lormont, near Bordeaux, of Etablissements Poliet et Chausson, which is claimed to be the most up to date of its kind in the world, started operation in August. With one kiln only, 100 metres long by 4.50 metres diameter, the works has a capacity of more than 600 tons a day. The total cost of the works is stated to be £362,289.

It is reported that Soc. Nouvelle des Chaux et Ciments H. de Villeneuve is about to erect a new cement plant at Cassis, to be equipped with Lepol kilns.

### German Cement Companies' Reports.

Portland-Zementfabrik Rudelsburg A.G.—Net profit for 1931, RM. 16,362 (£818), against RM. 44,287 (£2,214) for 1930. Dividend for 1931, nil, against 4 per cent. for 1930.

Portland-Cement-und-Kalkwerke Wilhelm Schlenkhoff A.G.—Loss for 1931, RM. 36,999 (£1,849), against profits of RM. 6,779 and RM. 1,188 for 1930 and 1931 respectively. No dividend has been paid for the past three years.

Basbecker-Portland-Zement-und-Tonwerke A.G.—Net loss for 1931, RM. 8,700 (£435), against losses of RM. 34,499 (£1,724) for 1930 and RM. 138,431 (£6,921) for 1929.

### Japanese Cement Companies' Dividends.

The following dividends for the year 1931 have been declared by Japanese cement manufacturing concerns: Onoda Cement Co., 5 per cent.; Iwaki Cement Co., 4 per cent.; Chichibu Cement Co., 6 per cent.; Ube Cement Co., 8 per cent.; Nanao Cemento Kabusiki Kaisha, 4 per cent.

### International Cement Corporation.

The International Cement Corporation, of New York, reports a net loss of 349,528 dollars (£71,919) for the quarter ended June 30 last, compared with a loss of 409,713 dollars (£84,303) for the preceding quarter.

### South African Cement Companies' Dividends.

For the year ended June 30, 1932, the net profit of the Cape Portland Cement Co. was £20,694, against £40,309 for the preceding year. A dividend of 6½ per cent. has been declared for the past year, compared with 10 per cent. for the previous year.

The dividend of the Pretoria Portland Cement Co., Ltd., for the year ended June 30, 1932, has been declared at 26½ per cent., with net profits at £171,691. For the previous year the dividend was 28½ per cent. and the net profit £194,932.

## The New Works of the Green Island Cement Co., Ltd., Hong-Kong.—III.

By HENRY POOLEY, Junr., B.Sc., Assoc.M.Inst.C.E., A.M.I.Mech.E.

CONSULTING ENGINEER FOR THE PLANT.

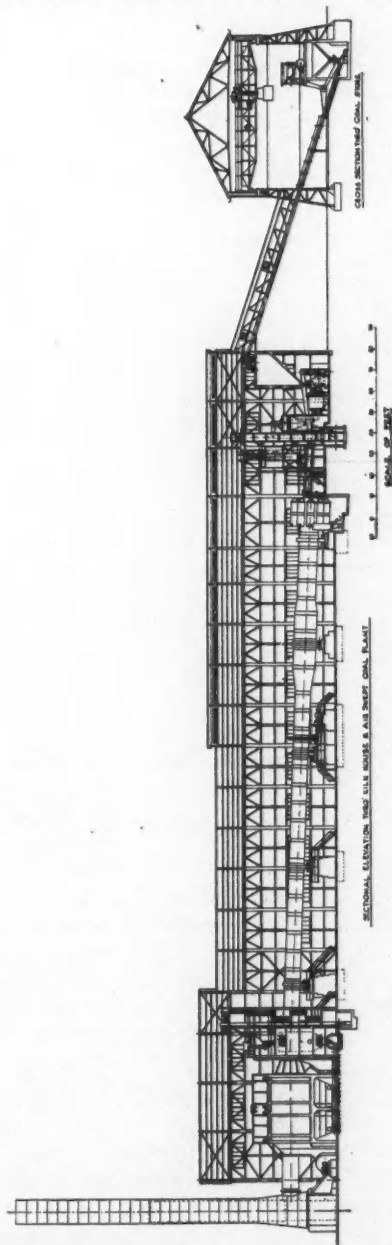
[MAIN CONTRACTORS: VICKERS-ARMSTRONGS, LTD.]

### Kiln and Coal Section (*Continued*).

The burner has under his control on the firing platform the regulation of the notch slurry-feeder, the operating of all the dampers, and the starters and regulating gear for all the motors connected with the operation of the kiln. It is therefore unnecessary for him to leave the burning platform in order to control any part of his plant, and an arrangement of red and green lights indicates to him if there is a stoppage of slurry from the main tanks.

The gases from the kiln pass first into a common brick flue lined with firebrick set in lime mortar. From this flue they can pass to a metal by-pass flue communicating directly with the chimney, which is 164 ft. high; the by-pass flue is also lined with firebrick. The chimney is built of mild-steel plates, riveted and self-supporting. The height of the steelwork is 150 ft., and this rests upon a 14-ft. concrete base. The diameter of the chimney inside the shell at the top is 10 ft. 9 in.

Normally, however, the gases from the kiln pass through Lodge-Cottrell electrical dust-precipitation plants, of which there is one for each kiln. These plants are of the normal Lodge-Cottrell construction and are contained in a concrete shell. The concrete of which the shell is composed is made from broken firebrick, sand, and cement, and from tests which were carried out the aggregate proved to be not far inferior in strength to limestone or granite. The voltage used for operating the Lodge-Cottrell plant is 60,000, stepped up from the 350-volt supply by rectifiers and necessary gear in the transformer house. Behind each precipitator is an induced-draught fan directly coupled to a 60-H.P. variable-speed motor with speeds from 360 to 575 R.P.M., which exhausts the gases into the base of the chimney. The motor driving the Lodge-Cottrell rectifier runs at 1,500 R.P.M., and is  $2\frac{1}{2}$  B.H.P., whilst the motor for operating each of the rapping-gear arrangements on top of the Lodge-Cottrell plants is  $1\frac{1}{2}$  H.P. As the dust-laden gases pass into the treater the dust is attracted to the highly charged electrodes; these are constantly rapped; and the dust falls into the hopper-shape bottom of each precipitator. Underneath each treater is a worm conveyor discharging into a conveyor at right-angles under the brick flue. A certain amount of dust is deposited in the brick flue and is extracted by five chutes to this cross worm-conveyor. The dust is fed in this manner to the boot of a totally-enclosed elevator, 8 in. wide by 59 ft. long, of the vertical chain-bucket type, driven by a 7.5-B.H.P. motor working at 720 R.P.M.; the con-



Green Island Cement Works : Sectional Elevation through Kiln House and Air-swept Coal Plant.

struction of this elevator is as previously described. The elevator discharges into one or other of two flue-dust hoppers furnished with directly-driven single-worm extraction gear, which transports the dust into an open conical hopper bolted to the kiln feed pipe, and the dust enters the kiln with the slurry as already indicated. The worm conveyors under the Lodge-Cottrell plant are operated by two 5-B.H.P. motors working at 725 R.P.M. The amount of dust reclaimed by the Lodge-Cottrell plant, as measured over a period, is 90 lb. of dust per ton of clinker.

The clinker from the coolers falls on to one or other of two shaker conveyors, each of which has a sufficient capacity for the output of clinker from four kilns, that is 24 tons per hour. The trough of each conveyor is built up of interchangeable 5-ft. lengths of  $\frac{5}{16}$ -in. mild-steel plate, stiffened on the top joints with mild-steel angles and slung at intervals of 10 ft. At the delivery end of each conveyor is a tapered bar screen to allow lump material to pass on to the rolls. Each conveyor feeds a set of 24-in. diameter by 18-in. wide geared and toothed crushing rolls. The pulley speed of the mill is 80 R.P.M. A 20-B.H.P. motor running at 720 R.P.M. drives on to a countershaft, and from the countershaft the shaker conveyor and roller mill are driven. One motor is required for each set of shaker-conveyor and roller mills.

The clinker discharges into one or other of two totally-enclosed vertical chain-bucket elevators, each having a capacity of four kilns, being 18 in. wide by 65 ft. centres and similar in construction to those already described for limestone. Each elevator is driven through reduction gearing by a 10-B.H.P. motor working at 725 R.P.M., and discharges either to an automatic tipping weighing machine, as already described for coal, or into a chute which can be used to spout clinker to one end of the store away from the outlets in the floor of the clinker store. This latter arrangement will only be used when a bad patch of clinker is suspected, or in the event of the clinker store being full. The capacity of this weighing machine is 15 tons per hour, and room has been left in the arrangement of the elevator to install a machine of twice this capacity at a future date should extension be deemed necessary. The weighing machine discharges on to a troughed-belt conveyor, 20 in. wide by 230 ft. long, which runs over the whole length of the clinker store, and is similar in construction to that described for crushed limestone, provided with an automatic travelling throw-off carriage which can be set so as to travel along the whole length of the store; in practice, however, it is found more convenient to fix the position of this carriage and to deposit clinker made at one time in one place in the store. This conveyor is operated through direct coupling by a 15-B.H.P. motor, working at 720 R.P.M.

The clinker store is separated from the kiln house and transformer station by a brick wall extending to the eaves to avoid the possibility of dust from the clinker entering either of these places. The other end is open to the air and where it abuts the road a concrete wall 7 ft. 9 in. high acts as a retaining wall for the clinker. The total capacity of the store, neglecting any clinker which can be spouted in the opposite direction, is about 11,000 tons. In the floor of

the store and running centrally down the middle are twenty gratings, each 3 ft. square and supported in a 2½-in. mild-steel angle frame forming part of the top of a small mild-steel hopper. These hoppers project into a concrete tunnel running under the full length of the clinker store, and under each hopper is an adjustable swinging chute for regulating the flow of clinker on to a troughed-belt conveyor 20 in. wide and 232 ft. long running in the tunnel under the store and which takes the clinker and delivers it to the boot of an elevator at the end of the store. This conveyor is driven by a 15-B.H.P. motor running at 720 R.P.M. through reduction gearing.

The clinker from the conveyor underneath the clinker store discharges into a totally-enclosed vertical bucket elevator having a capacity equal to four mills, that is 30 tons per hour. The buckets are 18 in. wide with elevator centres at 50 ft. apart, and the machine is driven by a 10-B.H.P. motor working at 725 R.P.M. through reduction gearing. The elevator discharges on to a troughed-belt conveyor 20 in. wide and 202 ft. long, driven by a 15-B.H.P. motor working at 725 R.P.M. The conveyor transfers the clinker from the elevator in the clinker store to an automatic weighing machine of the hopper type situated above the clinker bunkers in the cement mill. This machine indicates the quantity of clinker taken from the clinker store, while the automatic tipping weighing machine previously mentioned gives the quantity of clinker fed into the store.

#### **Cement Grinding Section.**

The clinker from the clinker store, after being weighed in the automatic scale, is tipped on to a 24-in. rubber and canvas flat belt conveyor, similar to that for distributing crushed limestone to the limestone bunkers. This conveyor, by means of ploughs, delivers the clinker into three reinforced concrete clinker bunkers. The clinker bunkers hold 215, 200, and 215 tons (untrimmed) respectively, and the gypsum bunkers hold 35, 40 and 35 tons respectively. The clinker conveyor on top of the limestone bunkers is operated through worm reduction gearing by a 7½-B.H.P. motor. There are five ploughs, the sixth opening in the bunkers being at the end of the belt.

A crusher with 20 in. by 6 in. opening, with manganese steel faces and toggle seatings, etc., and otherwise similar in construction to those used for limestone crushing, is provided on the ground floor to deal with gypsum. Gypsum is transported by hand from the dump under the ropeway to a small store alongside the gypsum crusher. An 8-in. totally-enclosed vertical bucket elevator of 52 ft. centres, and similar in construction to the other elevators described, transports the gypsum to the top of the concrete bunkers. This elevator is driven through worm reduction gearing by a 10-B.H.P. motor. A flat rubber and canvas belt conveyor 20 in. wide and 54 ft. long delivers the gypsum by adjustable ploughs to one or other of three small gypsum bunkers. The gypsum crusher and elevator are driven by a 20-H.P. motor with the necessary countershafting, while the gypsum conveyor on top of the limestone bunkers is operated by the same motor.



Underneath the clinker and gypsum bunkers there are 54-in. and 24-in. diameter feed tables respectively. The clinker and gypsum are fed into three 3-compartment compound ball and tube mills, each 6 ft. 6 in. diameter and 36 ft. long. With the exception of their length these mills are identical with those provided for the raw material and are driven by the same type and powered motor. As in the case of the raw mill the motor house is formed under the concrete bunkers and is separated entirely from the cement mill to avoid any dust. The first chamber of each mill, which is 7 ft. 1½ in. long, is charged with 3½ tons of 5-in. and 3½ tons of 4-in. steel balls. The second compartment, which is 9 ft. 1½ in. long, is charged with 4 tons of 2-in. and 4 tons of 3-in. steel balls. The finishing compartment, which as in the case of the raw mill is silex lined, is charged with 7½ tons of 1-in. and 7½ tons of ¾-in. cast-iron cylpebs. The output of each mill was guaranteed to be eight tons per hour for ordinary Portland cement to a 5 per cent. residue on the 180 by 180-mesh sieve. When grinding rapid-hardening cement, which the Green Island Cement Co. calls "Emeralcrete," the guaranteed output was 4.75 tons per hour when grinding to 1 per cent. residue on the 180 by 180-mesh sieve.

The cement from the mills discharges into either of two 14-in. archimedean conveyors, each 64 ft. long. Each worm conveyor is driven through a flexible coupling by a 7½-B.H.P. motor, and discharges into the boots of two 18-in. by 55-ft. centres totally-enclosed vertical bucket elevators as already described.

It is necessary to handle the cement manufactured in the old dry-process works by the same means and to mix it with the ordinary wet-process cement and to store it in the concrete silos. Cement from the dry-process works was wheeled in specially-constructed trucks, which were fed directly from the tube mill, to an elevator and conveyor, distributing the cement over open low bins. The cement is still wheeled from the old factory in these trucks, but they are now discharged through a specially-constructed dust-reducing hopper on to an inclined rubber and canvas belt conveyor 29 ft. long and 24 in. wide. This belt is operated through a countershaft by either of the motors which drive the 14-in. worm conveyors. In this way the dry-process cement is discharged into the boot of either of the 55-ft. vertical elevators.

The two 55-ft. elevators, each of which has a capacity for four mills and is operated by 10-B.H.P. motors, discharge into two worm conveyors 18 in. diameter by 27 ft. long which transport the cement across a gantry over the roadway between the cement mill and the cement silos. These are operated through worm-reduction gearing by two 7½-B.H.P. motors. From the worm conveyors the cement discharges into two other totally-enclosed vertical bucket elevators, which lift it to the top of the silos. These elevators have 18-in. wide buckets and are 65 ft. from centre to centre. Each is driven by a 15-B.H.P. motor.

In the cement mill there is a suction bag-filter of generous capacity for collecting the dust in the mill house from each point of discharge from the clinker belt, from the automatic clinker weighing machine, and from each point of discharge



from the gypsum belt. As a matter of fact these last points of suction are unnecessary as little or no dust comes from the gypsum. From these points the dust is all collected in one main flue, to which dust is also drawn from the six clinker and gypsum feed tables. A second main flue takes dust which is drawn from each mill discharge and from the first pair of cement elevators. The dust-laden air is drawn through stocking filters by a fan operated by a 45-B.H.P. motor. The dust is deposited on the inside of these filters, which are rapped by special gear; it then falls to the bottom of the filter and by means of a worm conveyor is transferred to the bulk cement passing to the silos. Owing to the extreme humidity of the Hong-Kong climate during the summer months it is necessary to steam-heat the dust-laden air to be filtered to prevent clogging the filter with moisture; a boiler is arranged for this purpose in the building adjacent to the cement mill.

*(To be continued.)*

**CORRECTION.**—On page 353 of the October issue of this Journal the second speed of the kiln should have been given as one revolution in 95 seconds, and not 25 seconds as stated. The first speed is 48 seconds and the second speed 95 seconds.

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#### **Canada Cement Company.**

The directors of the Canada Cement Company decided to defer payment of the cumulative preference dividend due on September 30th. The operation of the company during the present season has been on a considerably reduced scale owing to the depressed condition of the building industry, and it is considered advisable to maintain the liquid position of the company by deferring dividend payments.

#### **Australian Cement Company's Dividend.**

The Adelaide Cement Co. Ltd., has declared a dividend of 10 per cent. for the year ended May 31, 1932, compared with 12½ per cent. for the previous year. The net profit for these years was £17,980 and £21,238 respectively.

#### **Swan Portland Cement Co., Ltd.**

This Australian cement company announces a profit of £13,210 for the year ended February 1932, against £123,040 for the previous year and £117,538 for the year ended February 1930. The dividend for the past year is 9 per cent., compared with 9 per cent. for 1931 and 12½ per cent. for 1930.

#### **United States Cement Production.**

For the period January to August 1932 the production of Portland cement in the United States amounted to 49,650,000 barrels, compared with 87,581,000 barrels for the same period last year and 110,793,000 in 1930. The percentage of production to capacity was 34.2 in August 1932, compared with 60.2 in August 1931 and 81 in August 1930.

## Notes from the Foreign Press.

ABSTRACTED BY J. W. CHRISTELOW, B.Sc.

**Burnt Cement Clinker Brick.** W. N. JUNG. *Zement*, Vol. 21, p. 433, 1932.

Most Russian works now use cement clinker brick for lining the kiln clinkering zone, and a study has been made of the varied life of this lining in different works. The lining lasts longer in a kiln with enlarged clinkering zone than in a cylindrical kiln. The maximum life noted was 100 days, the average being fifty days. In different works the life varies between wide limits, showing that kiln control plays the most important part.

The changes in the structure of cement clinker brick in the kiln were studied, using samples obtained when certain wet-process kilns were stopped for repair. The bricks were covered with a protective layer of clinker which rapidly disintegrated on cooling. Considerable changes in the structure of the brick were evident from the colour changes and general appearance. The deeper layers were light brown in colour, and unchanged clinker nodules were embedded in cement containing many fine cracks. As the hot surface was approached the colour became dark brown. The yellowish layers could be readily broken up, but the darker surface layers were stronger and the clinker nodules were merged into the cement by incipient fusion. In the hottest zones the whole mass had clinkered.

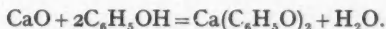
The resistance of cement clinker brick depends on the protective fused-on surface layer. This breaks away on stopping the kiln, hence the reduced life due to stoppages. To make the brick truly fire-resistant, before building it into the kiln it must be burnt at clinkering temperature (1,450 deg. C.) forming a homogeneous clinkered mass. In laboratory tests the best results were obtained by using 45 parts cement and 55 parts clinker (broken to 2 to 12 mm. diameter), and burning two days after making the bricks. The burnt brick is almost black and the surface shows a network of fine cracks.

Experiments were made with small amounts of various fluxes ( $\text{CaCl}_2$ ,  $\text{Fe}_2\text{O}_3$  and fluorspar) to reduce the clinkering temperature. The best results were obtained by adding 1 per cent.  $\text{CaCl}_2$  to the mixing water. Attempts were also made to make the bricks more resistant to alternate heating and cooling by additions of boric acid and  $\text{Cr}_2\text{O}_3$  to the cement used. Using 1 per cent.  $\text{CaCl}_2$  and 2 to 3 per cent.  $\text{Cr}_2\text{O}_3$  and burning at 1,450 deg. C., a well-clinkered brick was obtained which showed no disintegration after ten times heating to 1,450 deg. and subsequently cooling; without the  $\text{Cr}_2\text{O}_3$  there was considerable disintegration.  $\text{K}_2\text{Cr}_2\text{O}_7$  had the same beneficial effect. The fact that the  $\text{Cr}_2\text{O}_3$  works by preventing the formation of  $\beta$ -dicalcium silicate during clinkering led to a trial of adding  $\text{CaO}$  to the cement used, and excellent results were obtained from additions of 1 to 2 per cent.  $\text{CaO}$ .

The clinkering process gives a brick of twice the crushing strength of the unburnt brick at 28 days. It is hoped shortly to line a kiln with these burnt bricks and study the practical results.

**The Phenol Method for Determining the Free Lime in Cement.** By J.KONARZEWSKI and W. LUKASZEWICZ. *Zement*, Vol. 21, p. 533, 1932.

A method for the determination of the free lime in cement has been evolved which has advantages over the glycerine method. It depends on the solution of free CaO in a mixture of phenol and absolute alcohol, other calcium compounds remaining insoluble. The solution is filtered, the alcohol distilled off, and the residue diluted with water and titrated with HCl and methyl orange. The reaction is



On diluting with excess water the reverse reaction takes place and the  $\text{Ca}(\text{OH})_2$  formed is titrated with HCl.

The experimental details are as follows: (1) A 1:1 mixture of anhydrous phenol and alcohol is used. Both solvents are purified by distillation, the alcohol first over lime and then over calcium. The solvent must be prepared immediately before the analysis, and 25 c.c. are tested by distilling off the alcohol, diluting with water, and adding methyl orange; a single drop of N/15 HCl should give the colour change. 25 c.c. of solvent suffice for a determination. (2) The cement is rapidly finely powdered, taking care to avoid absorption of moisture and  $\text{CO}_2$ . 0.1 to 1.0 gramme is taken. (3) The cement and solvent are boiled for 3 to 8 hours in a 200 c.c. flask under a reflux condenser protected with a soda-lime tube. The time of boiling depends on the amount of free lime present. (4) The liquid is next filtered through a glass filter under vacuum, well washing with anhydrous alcohol. The alcohol is distilled off, the residue solidifying on cooling. (5) The phenol is melted by slightly warming, 100 c.c. distilled water and a few drops methyl orange are added, and the liquid is titrated with N/15 HCl.

The advantages over the glycerine method are (1) it is easier to obtain anhydrous phenol than glycerine, (2) only one titration of sharp end point is required, and (3) although the total time is the same the boiling proceeds without attention in the phenol method. The method has been proved to be accurate.

**The Problem of Hardening.** By K. WURZNER. *Zement*, Vol. 21, p. 243, 1932.

The following experiments throw light on the recent Kühl-Tippmann controversy.

Portland cement was mixed to a paste with concentrated  $\text{CaCl}_2$  solution and filtered. The filtrate, at first clear, becomes cloudy on standing and a white voluminous precipitate forms which can be filtered off to give a clear colourless filtrate. The addition of HCl to either precipitate or filtrate gives a deep yellow solution, obviously containing iron, 100 c.c. of the filtrate from the cement paste contained  $\text{Al}_2\text{O}_3$  16 mg.,  $\text{Fe}_2\text{O}_3$  4 mg., and a trace of  $\text{SiO}_2$ . The quantitative experiments indicated that the  $\text{CaCl}_2$  solution is able to dissolve the easily hydrolysed calcium hydro-silicates, hydro-aluminates, and hydro-ferrites from the cement. These are rapidly hydrolysed to hydrated  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ . It appears probable that the same reactions also occur on mixing cement with water. The possibility of the simultaneous formation of an adsorption compound of lime with the deposited silica may be left an open question. It is thus quite possible that clinker particles may be decomposed to hydro-compounds and thence to the basic compounds of which they are formed, and that the hardening of cement may be due in great part to physical forces.

**Exothermic Effect of Portland Cement Clinker Formation from Blastfurnace Slag and Limestone.** By H. E. SCHWIETE and H. E. VON GRONOW. *Zement*, Vol. 21, p. 497, 1932.

The generally accepted value for the exothermic effect of clinker formation is that of Nacken, viz., 100 gcal. per gramme of clinker. It was considered desirable to repeat Nacken's measurements with the increased precision of modern technique. The calorimetric measurement of the heat of solution of the finely powdered materials was again the method adopted, and the present paper reports the results obtained with a normal blastfurnace slag and limestone, using three different sequences of reactions. All measurements were made in a mixture of 60 c.c. 2-normal HCl and 60 c.c. 2-normal HF.

(1) In a repetition of Nacken's sequence the heat of solution of 1 gramme of clinker and that of 1 g. of raw meal previously heated to 910 deg. C. for several hours was determined. The difference gives the exothermic reaction = 168 gcal. per gramme clinker.

(2) Instead of dissolving the decarbonated raw meal, the heats of solution of the slag and of the CaO were determined separately, the results being proportioned in the ratio in which the materials go to form 1 gramme of clinker and then added. The heat of solution of clinker is subtracted from the sum, giving the exothermic reaction = 170 gcal. per gramme clinker.

(3) The undecarbonated raw meal (dried at 110 deg. C.) was dissolved, calculated allowances being made for the heat required for decarbonation and for the work done in expanding the CO<sub>2</sub> against the atmosphere. The difference between this final value and the heat of solution of clinker gave exothermic reaction = 169 gcal. per gramme clinker.

The results by the three methods are very close (168, 169 and 170 gcal. per gramme). The accuracy of the heat of solution determinations is  $\pm 0.5$  per cent., and the possible error in the value of the exothermic reaction is  $\pm 6$  gcal. per gramme.

A determination of the exothermic reaction using clay and limestone is in progress. A value which is even higher than these results is anticipated, since with limestone and slag certain silicates are already formed in the raw mix, the formation of which proceeds with evolution of heat.

**Magnesite Brick Resistant to Temperature Changes, suitable for Lining the Clinkering Zone.** By K. ENDELL. *Zement*, Vol. 21, p. 522, 1932.

From the point of view of its resistance to chemical attack, magnesite brick is very suitable as a lining for the clinkering zone but its susceptibility to changes of temperature has hitherto prevented its use. Magnesite bricks resistant to temperature changes can now be produced at an economical price, and there is no longer any reason why their use for lining the rotary kiln clinkering zone should not spread. The torsion which the new brick will withstand, both within the elastic limit and in the region of plastic deformation at 900 deg. C., is five times that of the normal magnesite brick. Rapid cooling tests from 950 deg. also show the new brick to behave satisfactory.

## Japanese Standard Specification for Portland Cement.

We have received a copy of the 1930 Revised Edition of the Japanese Standard Specification for Portland Cement, which has been translated into English by the Association of Japanese Portland Cement Engineers. An abstract of the principal features of the Specification is given below:

**SPECIFIC GRAVITY.**—The specific gravity shall be not less than 3.05.

**FINENESS.**—The residue on a sieve of 4,900 meshes per sq. cm. shall not exceed 12 per cent. by weight. The diameter of the wire of the sieve shall be 0.055 mm.

**SETTING TIME.**—Unless a specially quick-setting property is specified or required, the cement shall have an initial setting time of not less than one hour and a final setting time of not more than ten hours at a temperature of 15-25 deg. C., the time being taken from the moment of adding the water. The setting time shall be determined by means of the Vicat apparatus using cement paste of normal consistency. To determine the normal consistency, 400 g. of cement shall be kneaded with a measured quantity of water for 3 minutes from the moment of adding the water; the kneaded paste shall be filled into the Vicat mould resting upon a non-porous (glass) plate, and the surface of the paste shall then be smoothed off level with the top of the mould. The paste confined in the mould shall be placed under the rod (Tetmeyer type) of the Vicat apparatus; the rod shall be lifted so that the pointer indicates 40 mm. on the scale and then allowed to sink gently into the paste. The paste shall be of normal consistency when the rod settles to a point indicating 6 mm. on the scale.

For the determination of initial setting time the paste confined in the mould shall be placed under the standard Vicat needle for the initial set test (the cap, rod and needle with all attachment shall together weigh 300 g.); the needle shall then be lowered gently into contact with the surface of the paste and released, and allowed to sink slowly. This process shall be repeated until the needle, when brought into contact with the paste and released as described, does not pierce it completely. The period elapsing between the time when the water is added to the cement and the time at which the needle ceases to pierce the test block completely resting at a point indicating 1 mm. on the scale shall be the initial setting time.

For the determination of the final setting time the standard Vicat needle for the initial set test shall be replaced by the needle for the final set test (the cap, rod needle with all attachment together shall weigh 300 g.). The cement shall be considered as finally set when, upon applying the needle gently to the surface of the paste the needle makes an impression thereon, while the attachment of the needle fails to do so.

The standard rod shall be 10 mm. in diameter and 50 mm. long. The standard needle for the initial set test shall be 1.13 mm. in diameter by 45 mm. long and have a flat end. The standard needle for final set test shall be fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm. in diameter, the end of the needle projecting 0.3 mm. beyond this edge. The mould for the cement-paste is to be a non-porous ring 80 mm. in diameter by 40 mm. high.



**SOUNDNESS.**—Freedom from cracking due to expansion and also from warping shall be determined by the following soundness test, the so-called pat test, while the boiling test may be substituted as an accelerated method if the results of the normal pat test for twenty-eight days cannot be awaited. Two pats shall be placed in water about twenty-four hours after moulding and left there for twenty-seven days. The temperature of the water during the test must not be below 15 deg. C. For the boiling test, two pats shall, about twenty-four hours after moulding, be placed in a vessel filled with water, and the water shall be gradually brought to boiling point and kept boiling for one and a half hours. The pats shall be examined of soundness after the water has been cooled gradually to the room temperature.

To prepare the pats 100 g. of cement, with a sufficient quantity of water, shall be gauged into a paste, and a pat about 10 cm. in diameter, about 1.5 cm. thick at the centre, and tapering towards the edges shall be prepared on a glass plate. The amount of water to be used to make the paste shall be from 25 to 27 per cent. of the weight of the cement, and so regulated that the paste spreads out to the edge of the glass plate when the latter is lightly tapped on the edge.

**STRENGTH.**—The strength of cement shall be ascertained by compression tests from briquettes or tension tests may be permitted in place of them. The compression and tension tests shall be carried out with briquettes aged seven days (the first twenty-four hours in air, the remaining six days in water) and twenty-eight days (the first twenty-four hours in air, the remaining twenty-seven days in water); the strength shall be higher than the following: Compression, 220 kg. per sq. cm. at seven days and 300 at twenty-eight days; tension, 20 kg. per sq. cm. at seven days and 25 kg. per sq. cm. at twenty-eight days. The strength shall be the average strength of the six briquettes for each period. The briquettes used for the compression tests shall be cubes having sides of an area of 50 sq. cm. The briquettes for the tension tests shall have a least sectional area of 5 sq. cm. in the middle part, and the double lever type testing machine shall be used as standard.

The briquettes used for the compression and tension tests shall be prepared as follows: One part by weight of cement shall be mixed with three parts by weight of standard sand and distributed in the basin of the mixing machine (Steinbrück-Schmelzer type). The basin shall be turned twenty times, the predetermined amount of water then added, and the basin again turned twenty times. The mortar shall be filled into the mould (the inside is lightly oiled), the iron core inserted and beaten in with 150 blows of the standard hammer apparatus (Boehme Martens type); the superfluous mortar on the mould shall be sliced off and the surface smoothed. The turning of the basin and the hammering shall take about two and a half minutes each. The amount of water to be used for the mortar shall be such that after 100 to 110 blows of the hammer a moderate amount of water exudes from the under surface of the test pieces.

When the result of twenty-eight days test cannot be awaited it is permissible to determine compression strength by briquettes after three days hardening (the first twenty-four hours in air, the remaining two days in water) and seven days hardening (the first twenty-four hours in air, the remaining six days in water). The compressive strength of the briquettes shall be higher than 150 kg. per sq. cm. at three days and 220 kg. per sq. cm. at seven days. The strength shall be the average strength of the six briquettes for each period.

**MAGNESIA, SULPHURIC ANHYDRIDE AND LOSS ON IGNITION.**—The amount of magnesia and sulphuric anhydride shall not exceed the following: Magnesia (MgO), 3 per cent.; sulphuric anhydride (SO<sub>3</sub>), 2 per cent.; loss on ignition, 4 per cent.

## Water in Set Cement.

By F. M. LEA, M.Sc., A.I.C.,

OF THE BUILDING RESEARCH STATION.

THE distribution of water in set cement between various states has interested many investigators, and many methods have been used to separate the total water content into "free" and "combined" water, or into more elaborate subdivisions.

It has been said in a recent paper<sup>1</sup> that there are nearly as many definitions of "bound" water in colloid systems as there are methods of determination. This remark may well be applied to water in set cements, and it is the purpose of this paper to discuss briefly a number of methods which various workers have used to divide the water in a set cement into certain groups, and to examine what has actually been measured thereby. It will be seen from the discussion that any separation of the water in set cement into different classes contains elements of artificiality, and that the divisions obtained are determined by the particular way in which they are defined and have no unique significance. Nevertheless such divisions, provided their lack of any unique significance is appreciated, may be useful for certain purposes.

In general the methods which have been used depend on drying under arbitrary conditions of temperature and vapour pressure, freezing at a given temperature or extraction with a solvent.

The waters in set cement have been considered as made up of (a) water which is free and shows the vapour pressure and other properties of water in mass, (b) water which is condensed in fine capillaries and shows a reduced vapour pressure, or which forms part of the structure of the gel, and (c) water which is combined in hydrated compounds of definite chemical formulæ. Between the "free" water so defined and water showing a somewhat reduced vapour pressure due to the capillary structure in which it is held there can be no clear distinction, for there is not a sharp, but only a gradual, change in properties as the vapour pressure becomes reduced progressively. Most investigators have been content to adopt a simpler division into "bound" water and "other" water. This "bound" water has in some cases been intended to be only a measure of the water of type (c), and in other cases to include also part of that under (b). In some recent work Giertz-Hedström<sup>(2)</sup> adopted a preliminary classification of the water in a set cement into three groups which were considered to reproduce the theoretical grouping suggested. The three divisions were (1) free water which can be frozen out, (2) loosely combined water which cannot be frozen out, but can be dried out at 20 deg. C. under a water vapour pressure of 0.1 mm. Hg., and (3) firmly combined water which cannot be dried out under a water vapour pressure of 0.1 mm. Hg.

The water which is not removed when set cement is submitted to certain conditions of treatment is that portion whose vapour pressure has a value reduced

<sup>1</sup> D. R. Briggs, *J. Phys. Chem.*, 1932, 36, 367.

<sup>2</sup> S. Giertz-Hedström, *Teknisk Tidskrift*, 1930, 60, (50); *Kemi* (12) 89; 1931, 61, (2) *Kemi* (1) 1.



below that to which the system is being subjected. The amount of water not so removed must therefore vary with the vapour pressure under which it is determined. The "bound" water defined in any such way has then a definite value only when the vapour pressure to which it relates is defined.

The methods depending on drying out may be divided roughly into two groups, (a) those using ordinary temperatures with an atmosphere of low vapour pressure, and (b) those which use temperatures of 100 deg. C. or above. Examples of the first type are to be found in the work of Giertz-Hedström<sup>3</sup>, Gessner<sup>4</sup>, Jesser<sup>5</sup>, and Berl and Urban<sup>6</sup> who in one form or another have investigated the relation between water contents of set cements and the vapour pressure of the atmosphere with which they are in equilibrium. In the second group may be cited as examples the work of Endell<sup>7</sup>, Bates and Klein<sup>8</sup>, R. Wilson<sup>9</sup>, Work and Lassiter<sup>10</sup>, and Kraus and Jorns<sup>11</sup>.

Considering the first group we may take as an actual example the conditions of drying, 20 deg. C. at 0.1 mm. Hg, used by Giertz-Hedström. At 20 deg. C. the vapour pressure of water is 17.54 mm. The vapour pressure of any water which, at equilibrium, remains in the set cement under these conditions must then be so reduced as to be not greater than 0.1 mm. Now the vapour pressure, at constant temperature, of a gel is a continuous function of its water content and the water remaining in it will vary with the vapour pressure under which it is desiccated. Thus drying at any given vapour pressure only divides the water in the gel into two arbitrary groups as was clearly realised by Giertz-Hedström; the dividing line has no particular significance. It does not, however, even separate the gel water with a vapour pressure of 0.1 mm. or above from the water which is present in chemical combination in definite hydrates. Thus the compound  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 32\text{H}_2\text{O}$  is considered to exist in set Portland cement. It has been found in unpublished work at the Building Research Station that this compound remains stable down to a vapour pressure below 0.7 mm. at 20 deg. C., but that at 0.2 mm. it loses twenty-four molecules of water forming the compound  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 8\text{H}_2\text{O}$ . This compound again must lose its remaining water content at a still lower vapour pressure. It is seen, therefore, that the water lost from a set cement on drying under a vapour pressure of 0.1 mm. at 20 deg. C. must, if equilibrium be attained, include the greater part of the chemically combined water of hydration of calcium sulfoaluminate. Similarly Thorvaldson<sup>11</sup> found that the compound  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 12\text{H}_2\text{O}$  which can be formed from the hydration of tricalcium aluminate loses two molecules of water under a vapour pressure of about 3 mm. at 21 deg. C. and a further two at 0.2 mm.

<sup>3</sup> H. Gessner, *Kolloid. Z.*, 1929, 47, 160.

<sup>4</sup> L. Jesser, *Zement*, 1927, 16, 741; 1929, 18, 158.

<sup>5</sup> Berl and Urban, *Zeit. f. Angew. Chem.*, 1923, 36, 273, 568.

<sup>6</sup> K. Endell, *Zement*, 1926, 15, 823.

<sup>7</sup> P. H. Bates and A. A. Klein, *Bur. Standards Tech. Paper*, No. 78, 1917.

<sup>8</sup> R. Wilson, *Proc. Amer. Concrete Inst.*, 1929, 25, 522; also R. F. McMillan, *Eng. News Record*, 1929, 102, (15) 582.

<sup>9</sup> L. T. Work and P. Lassiter, *Concrete*, 1931, 38, (3) 81, (4) 89.

<sup>10</sup> F. Kraus and G. Jorns, *Zement*, 1930, 19, (45), 1054; 1931, 20, (14) 314, (15) 341.

<sup>11</sup> T. Thorvaldson, N. S. Grace and V. A. Vigfusson, *Canadian Jour. Research*, 1929, 1, (3) 201.

Similar steps in dehydration are likely also to occur with the hydrated calcium silicates. Calcium hydroxide also loses its water and is dehydrated at a vapour pressure of about 0.2 mm. at 20 deg. C. It may be concluded that not only can no value of unique significance for the gel water be thus obtained, but that the amount remaining in the gel at any given vapour pressure cannot be distinguished from that combined in definite hydrated compounds unless a correction for the amounts of these compounds and the water lost from them can be applied. Sufficient data for this does not at present exist.

Giertz-Hedström (*loc. cit.*) has tentatively suggested, from the form of isotherms which show the change of water content in a set cement with vapour pressure, that the water in a set cement may be divided into capillary water and absorbed water with a vapour pressure above 8 mm. Hg at 20 deg. C., and remaining water with a lower vapour pressure. While the use of a vapour pressure as high as 8 mm. may obviate loss of water of hydration from the set cement compounds, there is as yet no certain knowledge of this in regard to the hydrated calcium silicates. The division of the gel water itself at such a point is arbitrary, but it appears that the amounts of gel water remaining below this vapour pressure may be fairly small. It is possible, therefore, that the water retained under a vapour pressure of from 4 to 8 mm. at 20 deg. C. may in practice afford an approximate estimate of the water combined in hydrated compounds in a set cement.

Similar difficulties are met with in the method of drying at higher temperatures, such as 100 deg. to 110 deg. C. or above, for no clear distinction between gel water and water of hydration of definite chemical compounds can be made. Even if it could be assumed that all gel water were lost at say 110 deg. C., there is still the difficulty that both calcium sulfoaluminate and hydrated tricalcium aluminate lose part of their water of hydration at this temperature, and probably, the hydrated calcium silicate also. This method of examination of the water in set cement has recently been subjected to a critical study at the Building Research Station and its limitations and uses will be discussed in a subsequent paper.

The method of separating free water from bound water by freezing appears at first sight more hopeful, but it is subject to the same complications. The vapour pressure of water not frozen out at any temperature below 0 deg. C. must be so reduced as to be equal to that of ice at the same temperature. Thus at -10 deg. C. the vapour pressure of ice is 1.95 mm., that of supercooled water 2.15 mm., and hence the state in which unfrozen water is held must be such as to reduce its vapour pressure to 0.907 of its value for free water. At -5 deg. C. this reduction factor is 0.953, and at -20 deg. C. it is 0.823. The water not frozen out is therefore dependent on the temperature of freezing and is related to the vapour pressure of the system in the same way as with the desiccation methods. There is, however, a further difficulty.\* Soluble salts are present to a small, and variable, extent in all cements; these salts will be present in the "free" water

\* This difficulty arises in the desiccation methods only when the vapour pressure at which drying takes place is above that of the saturated salt solution.

in the set cement, depressing its initial freezing point and resulting in some "free" water remaining unfrozen at any lower temperature until the salt-water eutectic is reached. Owing to its low solubility the lime liberated from Portland cement will produce little effect; its saturated solution freezes at about  $-0.15$  deg. C. according to Guthrie.<sup>12</sup> The gypsum in the cement is rendered insoluble by formation of calcium sulphoaluminate and will also be without appreciable effect on the freezing point of the free water. Soluble alkalis are present in Portland cement to an extent which varies from a small value up to 1 per cent.  $K_2O + Na_2O$  or higher, and the effect of these on the freezing out of water becomes considerable. For the purpose of calculation the soluble alkali will be assumed to be entirely potash, since this is usually the predominant alkali constituent in Portland cements in this country, and to be present in the set cement as potassium hydroxide.

Consider 100 gm. of anhydrous cement which have been hydrated, and which contain 1 per cent. soluble potash. In the free water in the set cement 1.0 gm.  $K_2O$  is then present. Freeze the set cement at  $-10$  deg. C. From freezing point data on solutions of potash it is found that at  $-10$  deg. C. the solution in equilibrium with ice contains 1 part  $K_2O$  in 8.7 parts water. Hence an amount of free water equal to 8.7 gm. per 100 gm. of cement will remain unfrozen at  $-10$  deg. C., due solely to the presence of this soluble alkali. In the following table are shown corresponding values at  $-5$  deg.,  $-10$  deg.,  $-15$  deg. and  $-20$  deg. C. for a content of 0.5 per cent. and 1.0 per cent. soluble potash in the cement.

Per cent. soluble $K_2O$ in Cement.	Grams Water per 100 grams Cement remaining unfrozen at			
	$-5$ deg. C.	$-10$ deg. C.	$-15$ deg. C.	$-20$ deg. C.
0.5	7.4	4.3	3.4	2.8
1.0	14.9	8.7	6.8	5.6

A large amount of "free" water remains unfrozen at the higher temperatures due to the presence of soluble alkali, and the amount alters with variations in this soluble potash content. Giertz-Hedström (*loc. cit.*) found from the freezing method that the amount of free water in set cements varied from 0 to 30 per cent. depending on the age and initial water content of the sample; the majority of the values recorded were below 15 per cent. It is clear that the variable, and unknown, correction for the soluble salt effect represents a large proportion of the total value found, and may even exceed it. The freezing method\* therefore affords no definite distinction between "free" water and "bound" water, and, owing to the soluble salt effect, is open to more objections than suitably designed desiccation methods. The dividing line thus drawn by Giertz-Hedström between "free" and "loosely bound" water not only lacks any unique significance, as

<sup>12</sup> A. Guthrie, *Phil. Mag.*, 1878, (5), 6, 36.

\* It may also be noted that if the ice crystals are subject to pressure in the solid mass in which they are formed some alteration of the vapour pressure will occur. Any such effect will, however, be small unless the pressures become large.

is common to all methods, but varies in position for different cements according to their soluble salt contents.

An extraction method for determining free water in set cement was tried by Work and Lassiter<sup>9</sup>, absolute alcohol being the solvent. Since, however, the partial pressure of water vapour over an alcohol-water mixture is less than that of water the condition of extraction always corresponds to subjecting the system to some reduced vapour pressure. It results at equilibrium in the removal both of free water and of all bound water whose vapour pressure is not reduced below the particular value shown by the water in the solvent. The method, therefore, like the desiccation methods, only separates the water into two groups with vapour pressures above and below some arbitrary value.

The methods used for the separation of "combined" water from "free" and "gel" water have been shown to be arbitrary, and the relative amounts falling in the different groups to be a matter of definition; no fundamental chemical significance can therefore be attached to the values found. As Giertz-Hedström has suggested, the boundaries between the different groups may be fixed simply on utilitarian grounds, *i.e.*, in such a way, if possible, that the amounts of water falling in the different groups are related to the physical properties of the set cement or concrete. The reservation may be added that the method employed should be such that the dividing line drawn corresponds to the same reduced vapour pressure whatever the cement used.

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### Book Review.

**"Modern Coal Cleaning Plant,"** by Sydney H. North. Pp. 164. (London: E. & F. N. Spon, Ltd. Price 5s.)

Plant for the cleaning or washing of coal constitutes an important adjunct to colliery working, the amount of coal so treated in Great Britain exceeding 70 million tons a year and approaching 30 per cent. of the total coal output. This is a matter of direct interest to the cement industry because slack coal containing a proportion of ash that would render it unacceptable for firing kilns can be treated so as to remove a large portion of the dirt and yield coal containing less than 10 per cent. of ash, thus enlarging the market in which the cement manufacturer can obtain suitable supplies. The various methods of cleaning coal—both wet and dry—are described in this book, together with the auxiliary processes of grading to sizes and removing the water introduced by the washing process. The methods of testing to be applied to a coal to determine the effects of washing or dry-cleaning are described, and the economic aspects are discussed, leading the reader to conclude that coal cleaning is financially advantageous to the collieries and of benefit to many important industries where small coal can be used.

## New Cement Burning Process.

INCREASED economy of operation is one of the chief problems in the development of the rotary kiln for burning Portland cement. While possessing technical and mechanical simplicity, the high fuel consumption renders the rotary kiln far from perfect thermally or economically. For this reason efforts have been made to devise apparatus and arrangements whereby the large amount of heat in the waste gases may be used. One such arrangement is the installation of waste-heat boilers beyond the rotary kilns, but sometimes it is inexpedient to try to combine two such dissimilar processes. The utilisation of the heat in the waste gases by means of air heaters is difficult because of the very considerable amount of dust in the gases.

A new solution of the problem is an invention of Dr. O. Lellep, which has been described in several publications.\* The fundamental idea of this invention is the installation of a travelling grate in a chamber beyond the rotary kiln. The hot waste gases of the rotary kiln pass through this chamber above the travelling grate which conveys the raw meal in the direction opposite from the feed opening towards the rotary kiln. In order to obtain intimate contact between the hot gases and the cold raw meal particles, the gases are sucked through the layer of the raw meal and the travelling grate, and to ensure complete success in this exchange of heat it is necessary to introduce the raw material in a convenient shape. The invention of Dr. Lellep covers the forming of the raw meal into small nodules by the addition of a small percentage of water. The balls are in contact with one another only on very small surfaces and thus the layer of raw meal on the travelling grate in the form of nodules is easily permeated by the gases under suction. Furthermore, as the gases are thoroughly split up by the great number of small balls, an ideal transfer of heat from the gases to the nodules is obtained. With a layer of normal Portland cement raw meal 6 in. to 8 in. thick and a water content of 12 to 14 per cent. by weight on the travelling grate, such a perfect transfer of heat takes place when the waste gases have a temperature of about 1,650 deg. F. that the nodules at the bottom of the layer can be below 212 deg. F. while the upper layer may be calcined to a considerable extent. At the same time the average temperature of the exit gases will be about 300 deg. F., so that the travelling grate is not exposed to excessive temperatures.

This idea of using the sensible heat in the rotary kiln gases on the travelling grate by nodulising the raw meal shows striking advantages for the economical operation of such a plant. First, the waste gases can escape into the chimney at a low exit temperature, so that the waste heat losses are reduced to a minimum. Furthermore, the dust content of the waste gases is reduced to practically nothing because the lower layers of nodules on the grate, which have the lowest tem-

\*O. Lellep, Warmetechnische Untersuchungen über den Warmeaufwand beim Zementbrennen. Verbund-Rost-Drehofen. Dissertation. Techn. Hochschule Braunschweig 1930.  
E. Schirm, Brennen von Zement auf dem Wanderrost. Tonindustrie-Zeitung 1930, p. 978.



perature, are in most cases still damp and will absorb the dust particles like a filter. A plant using this principle will avoid practically all the losses of raw meal caused by the dust content of the waste gases. The uniform ball-shaped form of the nodules, which is retained during the burning, makes the clinker particularly suitable for being ground in the finishing mill. The evaporation of the water contained in the nodules leaves them porous, and during the burning process the clinker balls also remain porous, thus reducing their resistance to grinding.

Another advantage is the possibility of considerably shortening the length of the rotary kiln. According to the principles in use up to the present time, large kilns 330ft. or more in length have been used; the rotary kilns required for a Lepol plant, in order to finish the burning, will have a length of only 80ft. to 120ft. The mechanical construction of the kiln is therefore greatly simplified and the safety of working is increased. The operation is not rendered more

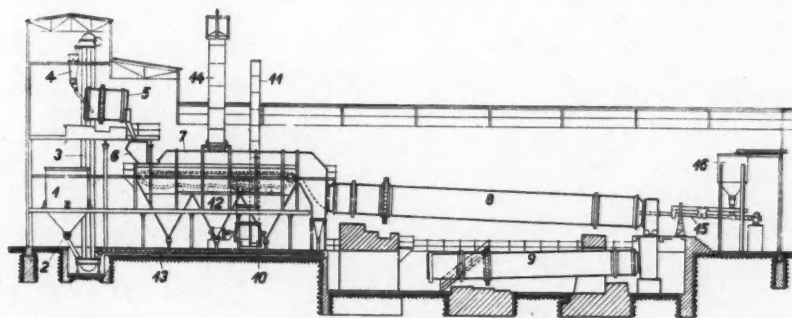


Fig. 1.—Diagram of Lepol Kiln.

difficult by the travelling grate, as the links are exposed to only a moderate heat.

This invention has been developed by Messrs. G. Polysius, A.G., of Dessau, who have introduced the Polysius-Lellep process in their Lepol kiln. The construction of the apparatus does not involve any difficulties of importance; in fact, a Lepol plant is distinguished by its simplicity. In addition to a short normal rotary kiln with powdered-coal firing and a normal cooling drum for clinker, there has been added a chamber for enclosing the travelling grate and a chute for connecting the chamber to the rotary kiln. A short "hydroballer" drum to nodulise the raw meal, with the addition of a quantity of water, is a necessary auxiliary part of the travelling grate equipment. The nodules are delivered directly on the grate by a hopper. As they pass through the chamber the water content is evaporated, and as the heat of the waste gases of the rotary kiln is absorbed they are partly calcined. Then they drop down a chute into the short rotary kiln, where the calcination is finished and in the hot zone of which the clinker burning is completed. The further procedure from the end

of the rotary kiln down the chute and through the cooling drum corresponds to normal rotary kiln plants. The clinker transfers a considerable part of its heat to the air, which is introduced through the cooler and which flows to the powdered coal flame as preheated combustion air. The noticeable heat of the clinker at the discharge represents an unavoidable loss of heat, but the short rotary kiln plant means a considerable reduction of the losses from radiation. The thermo-economical superiority of such a unit is recognised when the intense exchange of heat between the waste gases and the nodules is realised.

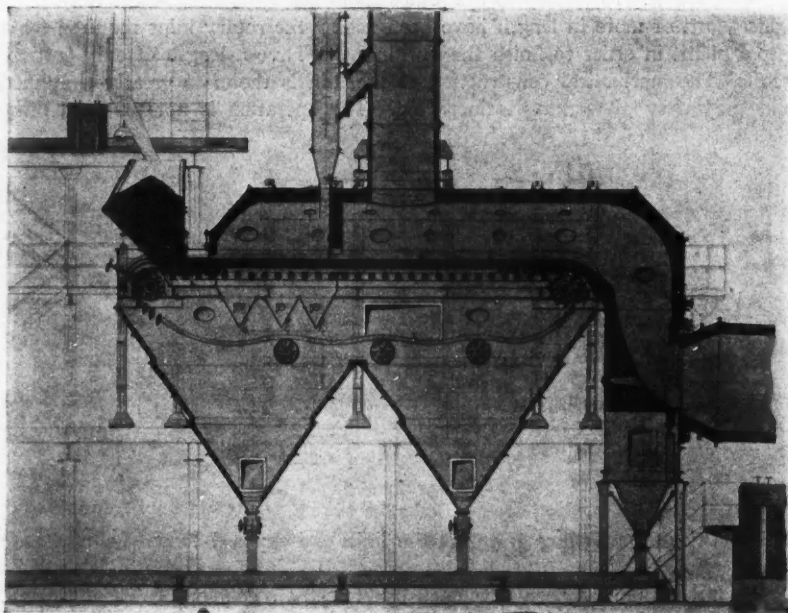


Fig. 2.—Longitudinal Section of Travelling Grate.

Fig. 1 is a diagram of a Lepol kiln. The raw meal is handled from a silo (1) by a screw, (2) and an elevator (3) into a small feeding bin (4). From this bin the raw meal is uniformly fed to a drum (5) where it is subjected to a fine spray of water, and by means of rotation the nodules are formed; these are collected in a hopper (6), which feeds the travelling grate (7). The material passes over the slowly moving grate to the kiln (8), and from the kiln in the usual manner to the cooler (9). The hot gases pass in countercurrent through the kiln and by means of a fan (10) are sucked through the layer of nodules and the grate (7), to be finally discharged through the stack (11). The particles falling through the grate are collected in air-tight and dust-tight hoppers (12) and returned to



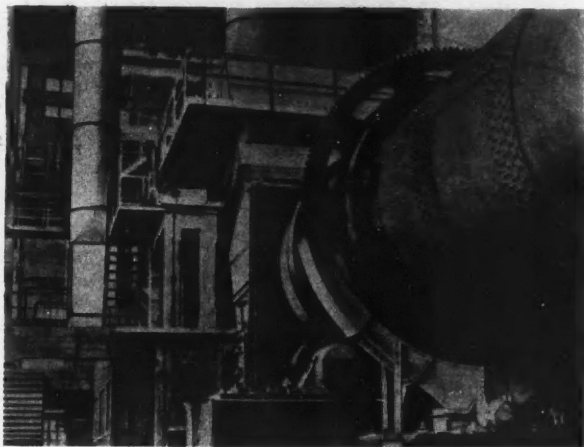


Fig. 3.—Upper End of Rotary Kiln with Connection to Travelling Grate.

the elevator (3) by a screw conveyor (13). On top of the grate enclosure is an auxiliary chimney (14) which can be closed by a flap damper and is used only in starting the plant; during normal manufacture it is closed, so that the hot gases are compelled to pass through the grate.

Fig. 2 shows a longitudinal section through the travelling grate. The chamber over the grate is formed by a casing of plate iron entirely lined with refractory blocks. Losses from radiation are avoided by a layer of heat-insulating material

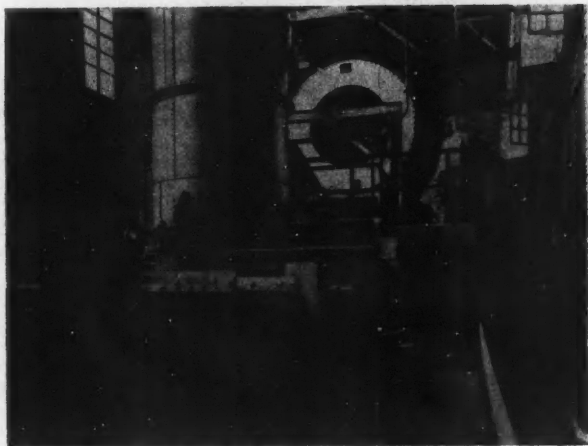


Fig. 4.—View of Grate Chamber with Hydroballer Drum above.

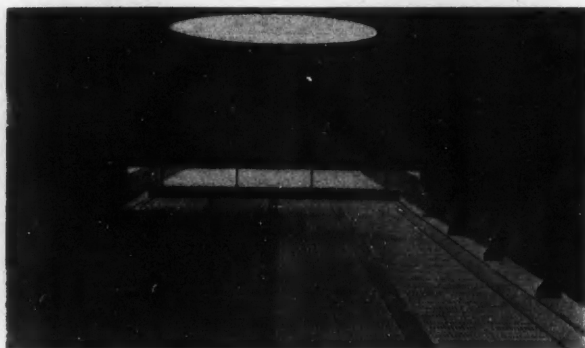


Fig. 5.—Interior of Grate Chamber before being lined.

between the plate-iron enclosure and the refractory lining. Fig. 3 shows the upper end of the short rotary kiln with bearing and drive, as well as the connection between the rotary kiln and the travelling grate. On the left hand is the chimney above the fan, while above the grate chamber the lower end of the auxiliary chimney is seen. Fig. 3 also shows how access is obtained to the different parts of the plant by staircases and gangways. Fig. 4 is a view of the grate chamber and the hydroballer drum above it. Fig. 5 shows the interior of the grate chamber and the surface of the grate, which is formed by inserting oscillating perforated grate bars of cast iron between strong chains of cast steel. Above, in the ceiling of the grate chamber (which is not yet lined) can be seen the opening for the auxiliary chimney. Fig. 6 shows the lower returning part of the grate chain, and also shows the grate links oscillating between the chains.

These illustrations were taken at a plant at San Sebastian, Spain, which is typical of a number of plants which have been erected.



Fig. 6.—Lower Return Part of Chain Grate.

The plant in San Sebastian was investigated thoroughly in order to ascertain the working economy, and the thermo-economical results, according to tests made on October 23, 1931, are as follows:

(1) *Kiln Output*.—The clinker was weighed on an automatic weighing machine immediately after leaving the cooler. During a 24-hour period there were 3,726 dumps of the tip-bucket, with an average load of 141 lb. of clinker. The total quantity was therefore 234½ tons, an average of 9.77 tons. The output per cubic foot of kiln volume was 3.79 lb. per hour, or 90.96 lb. of clinker per 24 hours, with an inside kiln volume of 5,756 cu. ft. and an effective grate surface of 258.3 sq. ft.

The temperature of the clinker at the outlet of the cooling drum averaged 660 deg. F. The temperature of the secondary air of combustion between rotary kiln and cooling drum was not measured, but according to measurements at other Lepol plants it will closely approach 1,380 deg. F.

(2) *Coal Consumption*.—During the period indicated there were fired 62,963 lb. of powdered coal consisting of two parts of a fat Asturian coal (Turon) and one part of Spanish anthracite. The analyses of these coals are given in Table I.

TABLE I.

TURON (FAT):							Per cent.
Water content (230 deg. F.)	..	..	..	..	..	..	0.56
Ash	..	..	..	..	..	..	9.34
Volatile matter	..	..	..	..	..	..	26.36
Lower heating power, B.T.U./lb.	..	..	..	..	..	..	13,200
ANTHRACITE (SPANISH):							
Water content (230 deg. F.)	..	..	..	..	..	..	1.10
Ash	..	..	..	..	..	..	19.73
Volatile matter	..	..	..	..	..	..	6.07
Lower heating power, B.T.U./lb.	..	..	..	..	..	..	11,980
MIXED (2 PARTS TURON, 1 PART ANTHRACITE):							
Content of water (230 deg. F.)	..	..	..	..	..	..	0.61
Ash	..	..	..	..	..	..	13.34
Volatile matter	..	..	..	..	..	..	18.55
Lower heating power, B.T.U./lb.	..	..	..	..	..	..	12,865
The ash of the mixture had the following composition:							
SiO <sub>2</sub>	..	..	..	..	..	..	48.25
Fe <sub>2</sub> O <sub>3</sub>	..	..	..	..	..	..	15.26
Al <sub>2</sub> O <sub>3</sub>	..	..	..	..	..	..	18.94
CaO	..	..	..	..	..	..	9.20
SO <sub>3</sub>	..	..	..	..	..	..	4.60
Remainder (probably alkalis)	..	..	..	..	..	..	3.75

The moisture content of the coal was 1.5 to 3 per cent. at the inlet of the drying drum and 0.5 to 0.8 per cent. at the outlet. The fineness of the powdered coal amounted to 0.1 to 0.4 per cent. residue on the 900-mesh sieve (76 meshes

per linear inch) and to 3 to 6 per cent. residue on the 4,900-mesh sieve (178 meshes per linear inch). If the moisture of the powdered coal, as fired, is assumed to average 0.6 per cent., this consumption of 62,963 lb. of wet coal would correspond to 62,586 lb. of dry coal. This is 11.9 per cent. of the weight of clinker. Based on the heating value of the powdered coal mixture of 12,865 B.T.U./lb the heat consumption is 581,500 B.T.U. per barrel, or 45.2 lb. of coal per barrel.

(3) *Composition of Raw Meal.*—Three kinds of stone are used, as follows :

	Margas high-lime. Per cent.	Arrobieta I low-lime. Per cent.	Amazonrain II. Per cent.	Andosin III. Per cent.
Loss in burning .. ..	36.75	32.67	38.38	43.38
SiO <sub>2</sub> .. ..	10.23	17.65	9.09	1.02
Al <sub>2</sub> O <sub>3</sub> .. ..	4.00	6.34	1.82	0.52
Fe <sub>2</sub> O <sub>3</sub> .. ..	2.00	2.56	1.14	
CaO .. ..	46.00	39.20	48.80	54.90
MgO .. ..	0.68	0.69	0.42	0.20
SO <sub>3</sub> .. ..	—	0.24	0.38	—
CaCO <sub>3</sub> (average) .. ..	72.00	77.00	86.00	98.00

For mixing the raw meal, three parts of limestone No. I and one part of limestone No. II are used, the composition being corrected by additions of the very pure limestone No. III.

#### EXAMPLES OF TWO RAW MEALS.

	I. Per cent.	II. Per cent.
Loss due to burning .. ..	35.36	35.88
SiO <sub>2</sub> .. ..	13.65	12.34
Al <sub>2</sub> O <sub>3</sub> .. ..	4.71	3.12
Fe <sub>2</sub> O <sub>3</sub> .. ..	1.69	2.80
CaO .. ..	43.68	44.04
MgO .. ..	0.88	0.23
CaCO <sub>3</sub> .. ..	77.2	78.0

The fineness of the meals is between 0.4 and 0.8 per cent. on the 900-mesh sieve (76 meshes per linear inch) and between 10.2 and 12 per cent. residue on the 4,900 mesh sieve (178 meshes per linear inch). Raw meal No. II was to be made expressly for the operation of shaft kilns, because at these kilns, which have a great loss of dust, there is a surprising reduction of lime content in the raw mix. In the case of the Lepol kiln there is scarcely any loss of dust, thus the lime content of the raw mix can be lower. For this kiln, mix No. I has been used.

The raw meal entering the Lepol plant is nodulised with the addition of 12 per cent. water and then drops to the grate. The sizes of the nodules, which were uniform in shape, are shown in the following screen analysis :

English sieve size.							Mesh opening.	Per cent. of each size.
No. 50	..	..	..	..	..	..	0.300 mm.	0.1
No. 30	..	..	..	..	..	..	0.589 "	0.3
No. 16	..	..	..	..	..	..	1.168 "	3.0
No. 8 ..	..	..	..	..	..	..	2.362 "	19.9
No. 4 ..	..	..	..	..	..	..	4.699 "	47.7
No. 3 ..	..	..	..	..	..	..	9.423 "	24.9
No. 2 ..	..	..	..	..	..	..	18.850 "	4.4

The original  $\text{CaCO}_3$  content of the (dry) raw meal, which is 77.2 per cent., must be considered in the calcination process. The remainder of the existing  $\text{CO}_2$  is combined as  $\text{MgCO}_3$  and must be taken into account accordingly. The nodules are fed on the grate in a layer 6.7in. deep and at a speed of 100ft. per hour (the speed of the driving shaft of the grate is  $12\frac{1}{2}$  revolutions per hour).

The temperatures in the first chamber (drying chamber) above the grate were measured directly by means of an iron-constantan-thermo-couple, and were as follows: Above the grate, 572 deg. F. (showing air leakage). Under the grate, below 212 deg. F. The draft corresponding to these conditions was: Above the grate, 0.394in. water column. Below the grate, 1.18in. water column. In the main or hot gas chamber the following temperatures were measured: Above the grate, 1,470–1,650 deg. F. Below the grate, 140–175 deg. F. (showing air leakage). The draft corresponding to these conditions was: Above the grate, 0.39in. water column. Below the grate, 2.36–3.94in. water column.

The temperature in the chute between the grate and the rotary kiln was 1,616 to 1,688 deg. F., which is sufficient for calcination. Analyses of the gas at the end of the rotary kiln were not taken, but the nodules were partly calcined (about 20 per cent.) when passing into the rotary kiln.

The quality of the clinker burned was good and remarkably uniform. The apparent porosity of the clinker nodules is a feature. No underburned or overburned clinker was found, nor any containing free lime. The analysis of the clinker was as follows:

									Per cent.
$\text{SiO}_2$	..	..	..	..	..	..	..	..	20.48
Insoluble	..	..	..	..	..	..	..	..	0.20
$\text{Al}_2\text{O}_3$	..	..	..	..	..	..	..	..	7.01
$\text{Fe}_2\text{O}_3$	..	..	..	..	..	..	..	..	2.97
$\text{CaO}$	..	..	..	..	..	..	..	..	63.85
$\text{MgO}$	..	..	..	..	..	..	..	..	1.38
$\text{SO}_3$ (including gypsum)	..	..	..	..	..	..	..	..	2.05
Hydraulic modulus	..	..	..	..	..	..	..	..	2.09

The qualities of the cement produced from this clinker can be seen from the following figures of results of tests made according to German standard specifications. The cement was ground in the laboratory mill with an addition of 3 per cent. gypsum, to a fineness of 4.8 per cent. residue on a 4,900-mesh sieve

(178 meshes per linear inch) and 0.2 per cent. residue on a 900-mesh sieve (76 meshes per linear inch). The setting time with 25 per cent. of water began at 2.45 hours and ended at 5.30 hours. Boiling, steam-drying and standard tests were passed satisfactorily.

Tests made according to German standard methods showed the following strength of mortar (with 8 per cent. water) :—

					Tension. lb. per sq. in.	Compression. lb. per sq. in.
After 2 days	..	..	..	..	459.5	5,148
After 3 days	..	..	..	..	497.8	5,973
After 7 days	..	..	..	..	550.4	7,083
After 28 days under water	..	..	..	..	589.3	7,908
After 28 days combined	..	..	..	..	722.5	9,061

(4) *Quantity of Air for Combustion.*—For combustion of the powdered coal a high-pressure blower is used, producing an average air pressure of 37.8 in. water column, with a capacity of about 1,893 cu. ft. per minute (calculated at an atmospheric temperature of 60 deg. F. and at a height of the barometer of 29.52 in. Hg). The amount of air required per hour is 113,590 cu. ft., which is used in conjunction with the consumption of 2,609 lb. of dry coal per hour.

On the heat balance to be made later on, the amount of excess air must be taken into account. That is, the ratio of the total amount of air furnished to that theoretically required amounts to 1.1 to 1.2.

The quantity of air theoretically required for complete combustion is about 99.5 normal cubic feet per lb. of coal; that is, about 120 normal cubic feet with excess air of 1.2. This requires 310,770 normal cubic feet of air per hour. The full output of 113,590 normal cubic feet of the blower is not used for the continuous maintenance of the combustion, but part of the air is returned by a valve to the suction side of the blower; 15 to 20 per cent. of the air required for combustion is therefore blown into the kiln as primary air.

#### THEORETICAL HEAT BALANCE.

For ideal kiln burning, without losses, and with a clinker exit temperature of 32 deg. F., the same exit temperature of the waste gases and the same initial temperature of the raw meal, and eliminating all losses due to radiation, transmission and convection, the following results will be obtained:

(1) *Heat Used.*—(a) Heating the raw meal from 32 deg. F. to the temperature of calcination (1,650 deg. F.), 380 lb. of clinker requires, with 35.56 per cent. of volatile matter ( $\text{CO}_2$  and  $\text{H}_2\text{O}$ ), 586 lb. of raw meal. The average specific heat of the raw meal from 32 to 1,650 deg. C. can be assumed as approximately 0.246 (calculated from the specific heat of the clinker and  $\text{CO}_2$ ). The resulting heat expenditure is thus 232,200 B.T.U. per barrel.

(b) The heat consumption for the dissociation of the calcium and magnesium carbonate in the raw meal is calculated from its  $\text{CO}_2$  content of 35.56 per cent. This equals 206 lb. in 586 lb. of meal, equivalent to 11 lb. of  $\text{MgCO}_3$  and 459 lb. of  $\text{CaCO}_3$ . Five pounds of the  $\text{CO}_2$  are to be driven out of the magnesium and 201 lb. out of the calcium carbonate. The heat consumption for this, for 1 lb.



of  $\text{CaCO}_3$ , amounts to 757 B.T.U. and for 1 lb. of  $\text{MgCO}_3$  to 370 B.T.U. Consequently for the raw meal the heat consumption is :

	B.T.U.
Dissociation of $\text{CaCO}_3$ .. .. .	347,500
Dissociation of $\text{MgCO}_3$ .. .. .	4,070
<b>Total</b> .. .. .	<b>351,570</b>

In the following heat balance no account is taken of the heat required for driving the water out of the clay substance in the marl of the raw meal. The general usage for the statement of heat balances of Portland cement kilns is adopted, according to which this heat consumption as well as the calculation of the loss of heat out of the water vapour in the waste gases is neglected. This is perhaps not quite correct, as, according to W. M. Cohn (German Ceramic Association IV 1923, p. 55), the amount of heat consumed for this is 169 B.T.U. per lb., but this would entail a correction of small importance to the heat balance.

(c) The heating of the calcined material from 1,650 deg. F. to the finishing temperature of 2,550 deg. F. can be assumed at this lower limit of 2,550 deg. F. owing to the porous quality of the clinker. The resulting specific heat of the clinker from 32 to 2,550 deg. F. is 0.257, and from 32 to 1,650 deg. F. is 0.234, and the heat consumption = 101,070 B.T.U. per barrel.

(11) *Heat Recuperation*.—(a) The exothermic effect of the formation of the clinker is beneficial to the economical heat consumption of the rotary kiln. The vitrification disengages, according to Nacken,\* about 100 calories per kilo, or 178 B.T.U. per lb. = 67,740 B.T.U. per barrel.

(b) The heat contents of the  $\text{CO}_2$  driven out at 1,650 deg. F. will be used again in the calcination and drying process; the average specific heat of  $\text{CO}_2$  (lkg.) from 32 to 1,650 deg. F. is 0.263, so that for the 206 lb.  $\text{CO}_2$  there are required for the calcination 87,385 B.T.U.

(c) Cooling of the clinker from its maximum temperature of 2,550 deg. F. to 32 deg. F. disengages at an average specific heat of 0.257 = 243,730 B.T.U.

The total theoretical heat balance therefore shows :

	B.T.U.
Heat used (Ia), (Ib), (Ic) .. .. .	=684,785
Heat recuperated (IIa), (IIb), (IIc) .. .. .	=398,855
Then the theoretical heat consumption for burning 1 barrel of clinker amounts to .. .. .	285,930

The real heat consumption for burning 1 barrel of clinker has been ascertained to be 581,500 B.T.U.; therefore, a relative efficiency of 49.3 per cent. compared with the theoretical is attained by the Lepol unit.

#### Practical Heat Balance.

	B.T.U. per barrel.
(1) Heating of the raw meal to 1,650 deg. F. .. .. .	232,145
(2) Calcination of the raw meal at 1,650 deg. F. .. .. .	351,570
(3) Heating of the calcined raw meal to the finishing temperature of 2,550 deg. F. .. .. .	101,070
<b>Total</b> .. .. .	<b>684,785</b>

\*R. Nacken, *Thermochemische Untersuchungen an Zementrohmehl und am Zement. Zement, 1922, p. 245.*

From these figures is to be deducted the recuperated heat as follows :

	B.T.U. per barrel.
(4) (a) The clinker waste heat from 2,550 deg. F. down to 660 deg. F., which is the temperature at the outlet of the cooler (specific heat, 0.257 and 0.209 respectively) .. .. .	194,145
(b) Heat recovered from the carbon dioxide gas liberated from the raw meal at 1,650 deg. F. down to exit gas temperature (about 300 deg. F.) .. .. .	75,665
(c) Exothermic heat developed in the chemical formation of the clinker .. .. .	67,740
Total .. .. .	337,550
(5) Evaporation of the water contained in the nodules fed to the grate with an average water content of 12 per cent.	
80 lb. of steam at 212 deg. F. .. .. .	90,975
Superheating to 300 deg. F. .. .. .	3,320
Total .. .. .	94,295
(6) Loss by clinker waste heat at 600 deg. F. .. .. .	49,585
(7) Waste gas losses :	
(a) Combustion gas volume, 171.3 normal cubic feet per lb. of coal, or, for 45.2 lb. of coal, 6,738 normal cubic feet of combustion gases. These have an exit gas temperature of 300 deg. F. . . . .	45,180
(b) The carbonic acid expelled from the raw meal has at a waste temperature of 300 deg. F. a heat content of . . . . .	11,720

The total quantity of waste gases amounts to 11,210 normal cubic feet per barrel of clinker. The fresh air infiltration below the grate is without importance for the heat balance.

Therefore the following practical heat distribution is attained in the Lepol plant :

	B.T.U. per barrel.
Raw meal fed to the kiln plant must be heated to 1,650 deg. F. This requires .. .. .	232,145
Calcination of the raw meal at 1,650 deg. F. requires .. .. .	351,570
Heating of the raw materials from 1,650 deg. F. to 2,550 deg. F. requires .. .. .	101,070
Total .. .. .	684,785
This quantity of heat includes 87 to 385 B.T.U. per barrel, which are contained in the carbonic acid expelled from the raw meal at 1,650 deg. F. However, 11,720 B.T.U. per barrel are lost as waste gas heat at 300 deg. F., so that only 87,385 - 11,720 = 75,665 B.T.U. per barrel can be used for the kiln process. These are to be deducted from the above .. .. .	75,665
Leaving .. .. .	609,120



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Furthermore, there is to be deducted the heat from the exothermal effect in the formation of clinker .. .. .

67,749

Remainder .. .. . 541,380

One barrel of clinker is thus produced, which has a temperature of 2,550 deg. F. and a heat content of 243,730 B.T.U. 49,585 B.T.U. are lost in the sensible heat of the clinkers, leaving the cooler at 660 deg. F., so that only  $243,730 - 49,585 = 194,145$  B.T.U. are transferred to the air for combustion. Consequently there are to be deducted .. .. .

194,145

Leaving .. .. . 347,235

There are to be added :

Loss of sensible heat in the gases of combustion which escape at a temperature of 300 deg. F. .. .. .

45,180

Loss of heat in water evaporated from the nodules at 300 deg. F. .. .. .

94,295

Total .. .. . 486,710

Loss by radiation, etc., as difference .. .. .

94,790

Effective heat consumed per barrel of clinker in the form of powdered coal .. .. .

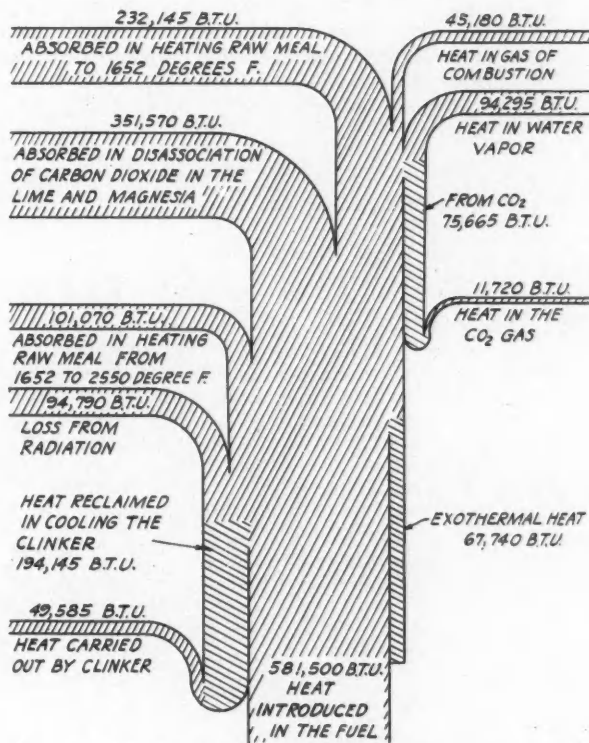
581,500

This distribution of heat is represented in Fig. 7. The following figures are shown graphically in the Sankey diagram, Fig. 8 :

	B.T.U. per barrel.	Per cent.
Theoretical heat consumption .. .. .	285,930	49.3
Water vapour .. .. .	94,295	16.2
Combustion gases at 300 deg. F. .. .. .	45,180	7.7
Carbonic acid at 300 deg. F. .. .. .	11,720	2.0
Radiation .. .. .	94,790	16.3
Clinker heat at 662 deg. F. .. .. .	49,585	8.5
	581,500	100.0

These combustion gases, when passing from the rotary kiln to the travelling grate, have a temperature of about 1,650 deg. F., which corresponds to a heat content of 260,800 B.T.U. There is still to be added the heat content of only that part of the carbonic acid which is expelled from the raw meal in the rotary kiln. Therefore it can be said that about half of the 581,500 B.T.U.'s per barrel in heat produced by combustion will be delivered to the grate.

These figures on the thermo-economical operation of the Lepol unit show a considerable superiority over previous rotary kilns. The question arises whether the adoption of the travelling grate and the power consumption necessary for its drive, as well as the necessity for the installation of a fan, the motor drive of the hydroballer drum, etc., require such a high power consumption that a considerable part of the thermo-economical advantages would be lost. A summary of the power consumption of the Lepol plant is as follows :



**Fig. 7.—Heat Distribution.**

								kW.
Hydroballer drum	..	..	..	..	..	..	..	18.5
Grate .. .. .	..	..	..	..	..	..	..	3.5
Rotary kiln .. .. .	..	..	..	..	..	..	..	20.0
Cooling drum .. .. .	..	..	..	..	..	..	..	12.0
High pressure blower .. .. .	..	..	..	..	..	..	..	13.5
Exhaust fan for the waste gases			..	..	..	..	..	42.0
Total .. .. .	..	..	..	..	..	..	..	109.5

This amounts to 2,628 kW.-hours per day, or 1.91 kW.-hours per barrel. The power consumption of a rotary kiln plant of the ordinary type will be as follows :

Mixing screw .. .. .	kW.
Rotary kiln .. .. .	25.0
Cooling drum .. .. .	29.0
Fan for powdered coal .. .. .	12.0
	22.0
	88.0

or 2,112 kW.-hours per day and 1.54 kW.-hours per barrel.

If one compares only the rotary kiln plants it appears that the power consumption of the Lepol kiln is somewhat higher than the normal rotary kiln, but this is compensated by the reduced grinding work to produce the powdered coal. If the power consumption of the powdered coal preparation section is assumed to be 32.7 kW.-hours per ton (2,000 lb.) of powdered coal, the following comparison results:

*Lepol Plant.*—11.9 per cent. powdered coal, or 45.2 lb. per barrel, or 31.2 tons per day = 1,030 kW.-hours per day or 0.75 kW.-hours per barrel of clinker.

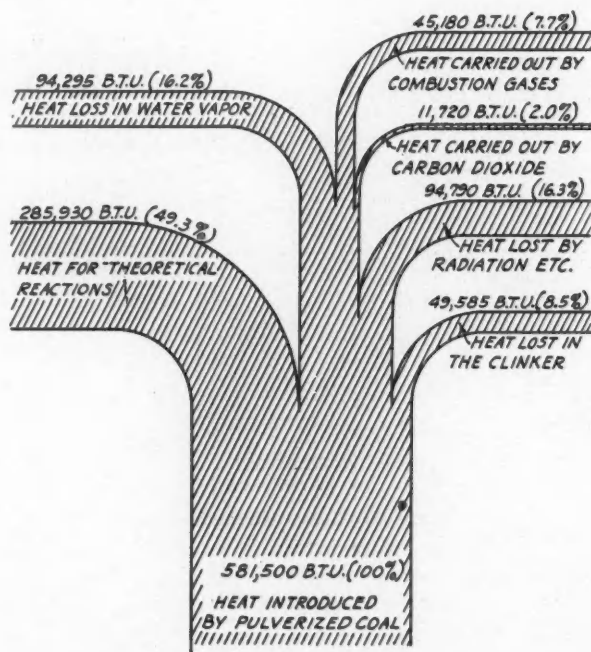


Fig. 8.—Heat Distribution.

*Normal Rotary Kiln Plant.*—An average of 1,017,000 B.T.U. per barrel = 20 per cent. powdered coal; this is 76 lb. per barrel of clinker, or 52.5 tons per day = 1,717 kW.-hours per day of 1.25 kW.-hours per barrel of clinker. Including the powdered coal preparation, the figures per barrel of clinker are as follows:

Lepol plant = 1.91 + 0.75 = 2.66 kW.-hours per barrel.

Rotary kiln plant = 1.54 + 1.25 = 2.79 kW.-hours per barrel.

The power consumption of a Lepol plant is, therefore, no more unfavourable than that of an ordinary rotary kiln plant.



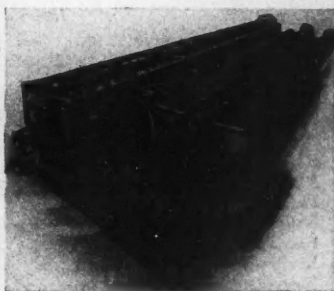
### Slag Cement Plant.

In addition to the report on the plant at San Sebastian, there may briefly be mentioned the analogous investigations at the Lepol plant of a slag cement works at Esch, Luxembourg. This plant was built for an output of 1,452 barrels of clinker; but because of conditions existing at this factory the Lepol plant can only be operated at approximately 80 per cent. of its normal output. For a short test period, however, the output of the plant was increased up to 1,599 barrels.

The preparation of the raw meal at this plant is a new pneumatic mixing system. The forming of nodules from the raw meal, containing blast furnace slags, offers no difficulties. In spite of the relatively unfavourable conditions of the low production rate, the coal consumption was considerably lower than the guaranteed coal consumption of 677,400 B.T.U. per barrel of clinker. In a test it was only 562,900 B.T.U. per barrel. The quality of the clinker is first class.

Comparing the Lepol plant with two old rotary kilns in the same works, it shows more economical production in spite of the unfavourable conditions under which it has had to operate. The average heat consumed in the old rotary kilns during a period of three months was 1,219,000 B.T.U. per barrel of clinker, while the Lepol plant at nearly the same production of clinker showed an average heat consumption of 569,000 B.T.U. per barrel for three months. It is to be supposed that the heat consumption of the Lepol kiln will be still more favourable when the plant can operate at a normal rate. The raw meal consumption of 589 lb. per barrel of clinker of the old rotary kiln plant was reduced to 529 lb. at the Lepol plant.

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## Notes from Abroad

### U.S.A. Cement Companies' Reports and Dividends.

The Bessemer Limestone & Cement Co. show a loss of 875,776 dollars for the year 1931, against a profit of 267,766 dollars for 1930.

The Lehigh Portland Cement Co. has declared the regular quarterly dividend of 1.75 dollars on the preferred stock, payable on October 1. The Secretary of the company stated: "In view of the substantial impairment to surplus and current available resources of the company within the past year it is apparent that improvement in the earnings of the company, which will be possible only in the event of an increased volume of trade, must in the future determine dividend action on the preferred stock." For the year ended June 30, 1932, there was a loss, after provision for depreciation and obsolescence, of 484,020 dollars, while for the second quarter of 1932 there was a loss of 406,386 dollars.

### Ketton Portland Cement Co., Ltd.

According to a recent Press report dealings are likely to take place shortly in the 6 per cent. Cumulative First Preference shares of the Ketton Portland Cement Co., Ltd., and the company now intends to double its producing capacity by the installation of a second unit. Including the new issue, which has been placed at 20s. a share free of stamp duty, the company's issued capital amounts to £445,101, of which £145,101 consists of 6 per cent. First Preference shares, £100,000 of 7½ per cent. Participating Preference shares, and £200,000 of Ordinary shares.

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